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Island Biogeography of the South Korean Coleoptera

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Abstract

Island Biogeography of the South Korean Coleoptera

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Since Island Biogeography that physical environment of islands such as island size or island distance affects biodiversity of them come to the fore, many biogeographers have tried to apply the Island Biogeographic rules to several isolated environments. Besides physical environment, however, human disturbance can also affect insular biota if island is not far from mainland and has undergone human disturbance, such as many South Korean islands. In this research, therefore, I comprehended distribution pattern of the South Korean insular Coleoptera and calculated the effect of the relationship between physical environment of islands and species diversity of Coleoptera. I also speculated the specific mechanism of distribution pattern of Coleoptera through collecting samples and testing the hypothesis.

Nestedness analysis result showed high nestedness value of South Korean islands for Coleoptera species and the possibility of geographical region of Coleopetran type species. The west coast generally tends to show higher nestedness than the southeast coast so that the west coast seems that undergoes less outside disturbance (human disturbance) such as invasive species from Korean peninsula.

Island size was directly proportional to species diversity. However, it was also inversely proportional in big inhabited islands. It is because the islands can support larger human population and undergo severe and continuous human disturbance. Island distance was not correlated with species diversity. However, island distance was directly proportional to the number of macropterous species in the high-nestedness regions. It suggests that macropterous species have advantage over brachypterous species in terms of reaching far islands and colonizing on their own in case of less outside disturbance.

To test the difference of distribution of Coleoptera with different wing length, four islands around Boryeong city in Chungcheongnamdo province were surveyed. 755 samples were collected using pitfall-trap and sweeping and identified. Identification result showed the tendency that dominance index was inversely proportional to island distance and the rate of macropterous species. It may be originated from the characteristic of macropterous species such as slow colonization and fewer individuals in restricted area. Therefore, the difference of dispersal ability with wing length may affect species composition of islands.

In this research, I calculated and speculated the effect size of classical Island Biogeographic theory and human disturbance in South Korean islands, and also found distribution pattern and the mechanism of the South Korean Coleoptera. This research can be used as base data when predicting species composition and species diversity of uninvestigated islands.

Keyword : Island Biogeography, species diversity, Coleoptera, macropterous species, brachypterous species
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Chapter 1. Introduction

1.1. Study Background

As a subject material of global research of biology, ecology and geography, island is evaluated as an attractive environment with various resources. Evolution and convergence of insular biota originated from the isolated environment attracted scholars' attentions. Furthermore, island is understood as an intermediator that link human, other living things and environment in terms of archaeology or environmental science. Thus, research about insular biota and ecosystem established itself as a basic one of ecology, and developed into island biogeography theory.

McArthur & Wilson (1967) established foundational framework of island biogeography theory. It was used to research ecological roles and function of lots of islands in Pacific Ocean. It is divided into two concepts: First, Big island has more species than small island. Second, island close to mainland has more species than island far from mainland. Based on these two concepts, colonization and extinction of species were theorized. The number of an island presents balance between immigration rate and extinction rate, which is known as equilibrium theory of island biogeography. In the narrow sense, island biogeography theory means this equilibrium theory. Size, isolation and age of an island is principle factors for the theory in the order named. Immigration rate is high in the case of big size, short distance and old age. Extinction rate is, on the contrary, high in the opposite case.

The island biogeography theory explained mechanism of species richness types in many archipelagoes, and the prediction through the theory was apposite. Field data of early researches provided empirical evidences for it (Simberloff & Wilson, 1969; 1970). The basic concept was extended to alpine region and cave(Culver, 1970; Vuilleumier, 1973). Alpine region is also

isolated with community isolated in the region, and cave entrance divides landscape structure of the outside and community in the cave. On the other hand, in accordance with urbanization and increase of linear terrestrial traffic routes in global scale, researches about habitat fragmentation began in earnest. Island biogeography theory spread fast because similarity between fragmented habitat and island was acknowledged easily. Especially, to prepare for catastrophic disturbances, how to set the number and extent of preservation area was that island biogeography theory could be useful to deal with.

However, the theory has been criticized, with data different from it. The hypothesis of equilibrium caused arguments above all. First, an island needs too much time to reach the equilibrium state (Simpson, 1974). The time accompanies geochronological disturbance that climate and other environmental factor change, and it causes disturbances before the ecosystem reaches the equilibrium state. Second, the equilibrium theory is not significant in the systems that undergo frequent catastrophic disturbance or disaster such as hurricane, regardless of island size (Ehrlich et al., 1980). This suggests that other factors are more important to explain insular species richness in the environment where natural disturbances are common. Trophic dynamics and other ecological process that affect colonization is also considered. If an island size is big enough, species relationship in the island such as predator and prey is more significant than physical environment of the island (Toft & Schoener, 1983). Third, the extinction concept in the theory is very minor and the reason of extinction is not accurate especially in ecological view (Williamson, 1981). Thus, the concept of immigration, extinction and species pool was defined poor. It also ignores historical data and the role of environmental change (Pregill & Olson, 1981).

Despite of many criticisms, however, effect of size and isolation exists certainly through many biogeographic researches. The theory had illuminated size and isolation of natural region could

correspond with the object of conservation in 1970s and 1980s. Since the work, substantial developments have been made in island biogeography theory with a plethora of mechanisms having been postulated to explain the structure and dynamics of insular communities (Lomolino et al., 2010). Classical equilibrium theory is regarded as a defective theory that cannot encapsulate the dynamics and complex nature of insular biota (Lomolino, 2000; Hortal et al., 2009; Franzén et al., 2012; Helmus et al., 2014). We must examine not only the size and isolation of islands but other factors of the islands and species under consideration (Nakamura, 2015).

Subsequent studies have documented the importance of island characteristics, such as habitat complexity (Jonsson et al., 2009; Kotze et al., 2000), which may be related to niche dimensions and breadths, prey–competition and the number of predator (Buckley & Jetz, 2007) and available niche range (Götzenberger et al., 2012). There is a broad consensus that much of the variation in diversity is explained by island size with other factors playing minor roles (McMaster, 2005; Kalmar & Currie, 2006; Kreft et al., 2008)

Recent studies have highlighted the influence of human disturbance, such as land use and introduction of invasive species, on island biotas. Compared with continental systems, islands are more vulnerable to the introduction of exotic, invasive species and may completely alter ecosystem functioning. Agriculture or constructing man–made features conducted in islands can occur enough disturbances. Furthermore, an increase in human visits and transport of goods to islands leads to increased propagule pressure and the likelihood of introduction of invasive species (Lonsdale, 1999; Pyšek & Richardson, 2006; Nakamura, 2015). Beside those, human population (Rizali et al., 2010), vegetation density (Cardoso et al., 2010), resort existence (Nakamura et al., 2015) and number of visitors (Nakamura et al., 2015) have been also suggested. Those factors come from the characteristics of each island. Because each island shows different physical and ecological

environment and the type and degree of disturbance it undergoes.

South Korea has about 4325 islands and more than 75% of them distributes around west and south coast. Since the formation of the west coastal islands of Korea result from sea level rises, most of the islands have historically undergone human disturbances, such as human settlement or visit, agriculture and introduction of invasive species. Therefore, surveying and analyzing biota and community of west coastal islands of South Korea is critical to understand a role of classical island biogeography theory and human disturbance when it comes to reflecting recent trend of island biogeographic researches and contributing to conservation of unique insular communities. Furthermore, it can help environmental researches as basic data recording relatively veiled ecosystems and values of the west coastal islands of South Korea.

1.2. Regional and Temporal Settings: Sapsido, Hodo, Nokdo and Oeyeondo on the West Coast of South Korea

The west coast of South Korea is part of Yellow Sea, one of the coastal sea located in the north side of Western Pacific region. The average depth is 44m, and the deepest part is 103m. Considering sea level change in Quaternary, Yellow Sea region was land all around because sea level difference was more than 100m in Last Glacial Maximum. Its eastern coast (west coast of South Korea) presents well-sorted sand formed by strong tidal current. In common with Korean peninsula, the west coast of South Korea is affected by East Asian Monsoon (EAM). In summer, therefore, climate of that region is normally hot and humid, and southeaster prevails. On the contrary, it is cold and dry, and northwester prevails in winter.

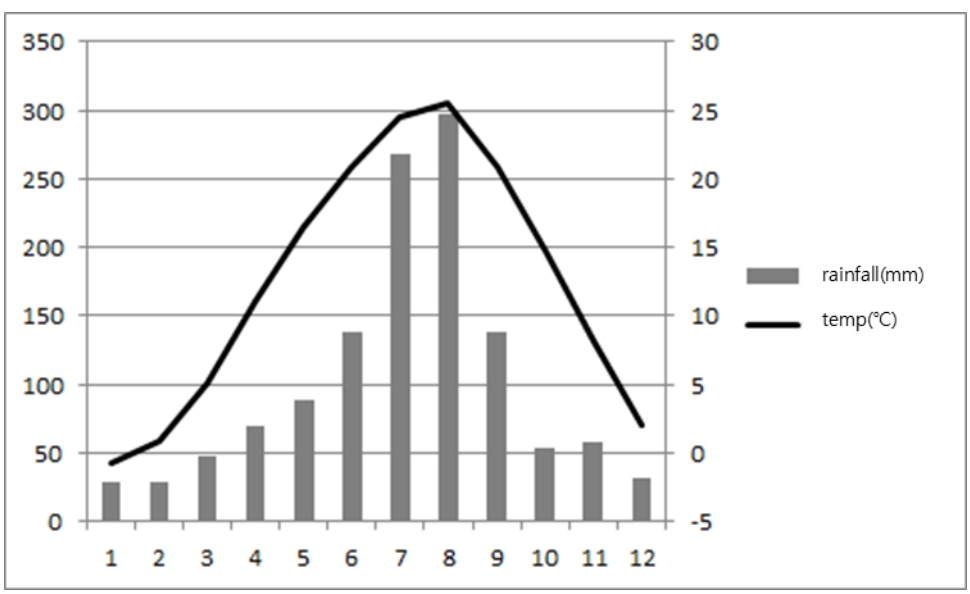

Figure 1. Climate data of Boryeong city, the west coast of South Korea(1981-2010)

On the west coast of South Korea, Sapsido, Hodo, Nokdo, Oeyeondo are critical islands to measure the effect of physical environmental factor of islands and human disturbance factor, which can affect insular species and communities. These four islands have adequate size that biota colonization works somewhat stably and show different characteristics of island environment and types of human disturbance.

Sapsido is located at 36° 19′ ~ 36° 21′ N, 126° 20′ ~ 126° 22′ E, 13.2㎞ from mainland. The area is 3.78㎢, the third largest island in Chungcheongnamdo province. Its landform presents low flat hill areas and sand hill except the southwestern high spot (113m above sea level). Different from other islands, Sapsido shows various vegetation landscape such as pine tree (dominant species), azalea and bamboo, but also shows additional landscape – rice paddy. There are many ponds and enough fresh water. Its short distance from mainland, diverse landscape, many accommodations, well paved road are favorable for tourists, thus, many tourists visit there.

Hodo is located at 36° 29′ ~ 36° 30′ N, 126° 25′ ~ 126° 27′ E, 22.5㎞ from mainland. The area is 1.30㎢. The landform presents low and flat hill areas and eastern sand hill. This sand hill is a representative tourist attraction. On this account, tourism demand is high. Hodo–mainland round–trip ship sails additionally in a peak season in common with Sapsido. Pine trees and vines are observed well, and several crop species are observed in narrow fields. There is no road that cars can pass.

Nokdo is located at 36° 26′ ~ 36° 28′ N, 126° 26′ ~ 126° 27′ E, 25㎞ from mainland. The area is 0.92㎢. The landform presents rocky ground with steep slope, and the high spot is 106m above sea level. There is no popular tourist attraction like beach or sand hill. Furthermore, accommodation or convenience store for tourists does not exist. Only a few anglers visit this island. In common with Hodo, pine trees, vines and several crop species are observed well.

Oeyeondo is located at 36° 22′ ~ 36° 23′ N, 126° 06′ ~ 126° 09′ E, 53㎞ from mainland. The area is 1.53㎢. The center is flat land, and mountains exist eastern (273m above sea level) and western side (175m above sea level). There is no sand hill, but evergreen forest consist of camellias and silver magnolias is a popular tourist attraction of the island in summer. In addition, pine trees, vines, crops are observed well in common with Sapsido, Hodo and Nokdo.

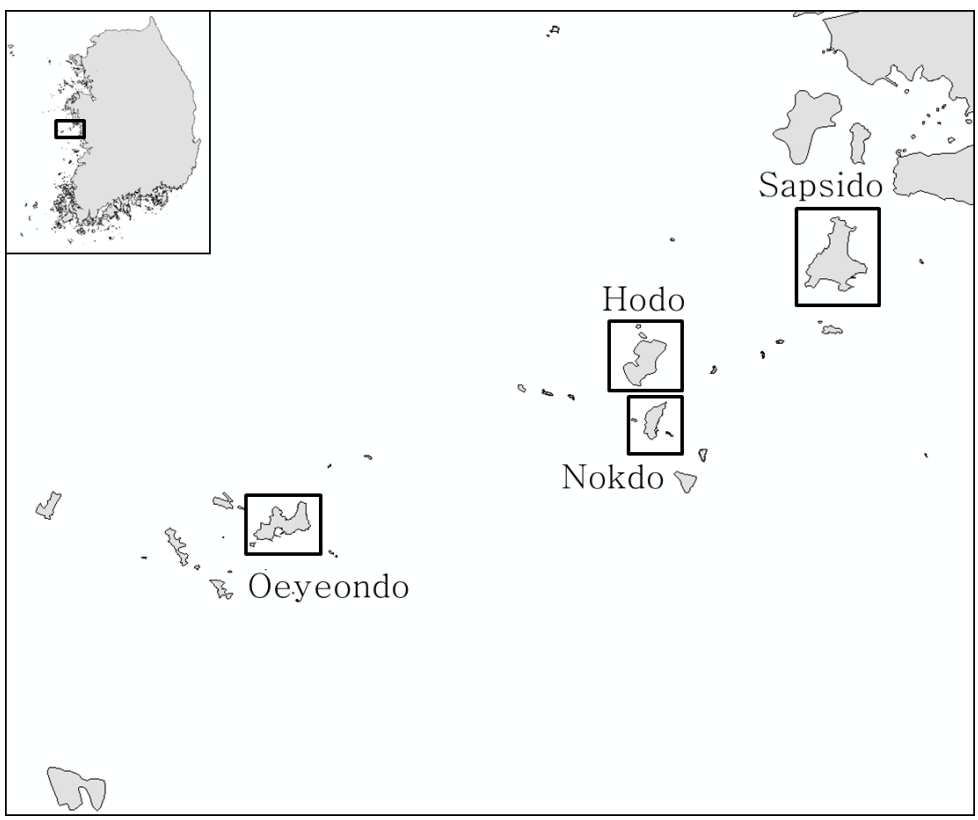

Figure 2. Map of Sapsido, Hodo, Nokdo and Oeyeondo

Factor	Sapsido	Hodo	Nokdo	Oeyeondo
area(㎢)	3.78	1.30	0.92	1.53
human population (2013yr.)	464	223	195	451
rate of cultivated area(%)	18.78	10.77	16.30	9.8
distance from mainland(㎞)	13.2	22.5	25	53
number of annual ferry visits	1157	792	730	730
number of visitors	large	large	Small	medium

Table 1. Environmental Summary of Sapsido, Hodo, Nokdo and Oeyeondo

Thus, Sapsido, Hodo, Nokdo and Oeyeondo show several similar environment factor (dominant vegetation, altitude and adequate size of stable biota colonization) and different factors. Finally, these four islands are aligned in a line from mainland, although there are many small islands near the four islands. This fact has an advantage for measuring the different effects depending on distance between island and mainland.

1.3. Research Purpose and Structure

In this study, Coleoptera communities and distribution in Sapsido, Hodo, Nokdo and Oeyeondo will be surveyed and understood. Through analyzing Coleoptera samples by surveying Sapsido, Hodo, Nokdo and Oeyeondo that indicate different environmental type and different human disturbance of the west coastal islands of South Korea well, ecological characteristics affecting colonization of Coleoptera per island can be inferred. It is because insular Coleoptera species and communities adapt to the distinctive environment including stress and disturbance, so they reflect how their habitats adapt them and give stresses to them, showing different significance of each environmental and human factor. Based on this result, this study could be helpful to understand and predict Coleoptera communities inhabiting certain environment similar with the west coastal islands of South Korea.

To sum up, the purposes of this research are to:

1. Identifying Coleoptera community and different ecological characteristic per island.
2. Organizing relationship between insular Coleoptera community and island environment in the west coastal islands of South Korea.

The literature review related to this study is explained in Chapter 2, including the introduction to Coleoptera. The methodology, is introduced in Chapter 3: how to collect Coleptera samples, how to identify samples, and how to measure ecological indices to evaluate the communities. In Chapter 4, the results of identification and measured ecological indices are described. In Chapter 5, the results from the previous chapter are interpreted, and relationships between the interpretation and characteristics of each island described in Chapter 1 and Chapter 2 are discussed.

Chapter 2. Literature Review

2.1. Introduction to Coleoptera

The name Coleoptera comes from Greek word koleopteros (κ ο λ εόπ τ ε ρ ος), which means hard wings like sheath(koleos) and wing(pteron). In English, it is often called beetle, which comes from the old English word bitela(biter). Beetles are a group of insects that form the order Coleoptera. Coleoptera is the largest of all orders, constituting almost 40% of described insects and 25% of all known animal life-forms (Bouchard et al., 2011; Hunt et al., 2007). And new species are discovered up to recently.

Coleoptera is evaluated as an insect group preserving ancestral traits in its low-taxon groups, so reasonable homogeneity of physiological constraints, body size and morphologies is main characteristic of Coleoptera. The general morphological characteristic of Coleoptera is outlined as follows. Thick and hard elytra of Coleoptera are divided into left and right, which meet on the midline of its back. However, several groups have soft elytra, such as Cantharidae (Philips et al., 2013). Elytra are not used for flight, but cover the hind part of the body and protect the hind wings. Membranous hind wings are often folded under the elytra or degenerated. Most of Coleoptera have mandibulate mouthparts with mandibles for chewing food. Compound eyes are developed well, but ocellus is not identified except some species. The shape of antennas is various per species, which is often used for courtship behavior and fight between males. The prothorax is big and can move because it is not stuck to the abdomen, but the mesothorax and the metathorax cannot move because they are attached each other. Coleoptera groups have adapted to a wide variety of food sources and habitats.

Coleoptera species are the prey of many animal predators including mammals, reptiles, birds, amphibians, fishes, spiders and

insects. A few carnivorous groups often feed on other Coleoptera groups. Most of their digestive system adapt for a herbivorous diet. On this account, many species damage stems and leaves of plants including crops, so they are classified as pests. For example, rice leaf beetle (*Oulema oryzae*) and many Chrysomelidae groups have damaged South Korean agriculture by nibbling away rice leaves.

The very origin of Coleoptera is not determined clearly. The earliest known Coleoptera fossils date to the Permian period (291.5–253 Ma). However, these members have 13–segmented antennae, elytra with more fully developed venation and more irregular longitudinal ribbing, and abdomen and ovipositor extending beyond the apex of the elytra. By the end of the Permian period, the elytra had evolved to a point that it was very much like the Coleoptera of today. The size became smaller than before. They became mostly aquatic; few terrestrial Coleoptera remained. However, Coleoptera would eventually return to the land. At this stage, Coleoptera had spread to most parts of the world. Late Permian Coleoptera fossils have been discovered in North America, Europe, Asia, Brazil, South Africa and Australia. Coleoptera is estimated as the first insect to pollinate flowers.

Coleoptera is studied as itself or used as several indicators to environmental evaluation, climate, communities and so on. In the point of the former, its phylogeny, physiology and behavior, ecological niche, distribution, migration route, adaptation are principle research subjects. In the point of latter, otherwise, several Coleoptera groups are good environmental indicator because of its tolerance of extreme environments. Its diapause, abundance, state of community and etc are often used. On the other hand, its specific traits are studied to have wide application to human life. Nano–particle ink used for field of certification and security of currencies was developed, emulating structural color of elytra of Coleoptera.

Same with other insecta groups, the flight ability is a critical component of dispersal in Coleoptera. However, individuals of larger Coleoptera species tends to disperse between habitat patches

more frequently than those of smaller species while other insects have decreased their body size to increase dispersal ability in their evolutionary process (Roslin & Tomas, 2000). This relationship is not necessarily evident among several clades because of different locomotion modes. For example, several Ipidae species were recorded that they can disperse up to 100㎞ in a single day via high-altitude flights, taking strong air current despite of their small body length, about 8㎜ (Jackson et al., 2008). Nevertheless, in absence of special event (i.e. typhoon, flotsam and birds) or continuous air current, it is not easy for most of Coleoptera species to reach faraway site on their own pure dispersal ability.

2.2. Studies on Island-Biogeographic Approach in South Korea and Abroad

There has been lots of island biogeographic research using Coleoptera lineage or community. Since island biogeography had been founded by McArthur & Wilson (1967), diverse topics and analyses have been developed: identifying and interpreting biogeographic patterns of islands (Fattorini, 2002; Morrone, 2006), the relationship between traits or diversity of island groups and physical environment of islands (Davies & Margules, 1998; Davis et al., 2002; Oertli et al., 2002;), dispersal patterns and vicariance with reference to geological or human events (Sanmartin, 2003; Claridge et al., 2017), the degree of being affected by habitat disturbance (Zabel & Tscharntke, 1998; Nakamura et al., 2015) and so on. Researches using Coleoptera as a clade of Arthropod has been often conducted because it is easy to understand arthropod communities than using just Coleoptera groups. Other arthropod groups such as Arachnida or Hymenoptera have low locomotivity in common with Coleoptera and form ecological association with Coleoptera.

The subject islands of biogeographic research about Coleoptera are also diverse. Archipelago has been popular environment for many biogeographers; researches surveyed in Europe, North America, Asia, Oceania accounts for island biogeography of Coleoptera: Caribbean Sea, Polynesia, Micronesia, Melanesia, British isles, Mediterranean Sea, Australian islands and so on. Furthermore, island biogeography theory has been applied to terrestrial environment. Aquatic or alpine species are similarly affected by the physical factor of the pond or alpine region in several cases (Oertli et al., 2002; Maveety et al., 2013).

In contrast with the situation in other countries in the world, island biogeographic researches in South Korea are very calm. Most of researches are conducted to comprehend and record natural environment of islands simply except few ones. Therefore, even

traditional biogeographic topic (distinguishing traits or communities of island species) has not been considered frequently, although island biogeographic research includes the process that records island species through surveys.

South Korean island biogeographic approach or analysis in the narrow sense is divided into two ways, which are introducing or discussing application possibility of island biogeography, and researching ecological communities or particular taxonomic groups in practice. The latter is mainly concentrated on communities of flora, butterfly. Kim et al. (2007) introduced island biogeography theory and history of it with reference to landscape ecology. Hong (2011) discussed distinct geographic characteristics of islands that affect distribution of living things and the importance of focusing on mutual relationship between man and nature systems of islands based on geographical, biological and ecological history. Choi (2000) analysed the relationships between butterfly species number and island area, latitude, and maximum elevation for butterflies in the Korean islands. Developing the research, Choi (2004) revealed a marked peninsula effect in South Korean butterfly species richness. Chung and Hong (2002; 2006) analysed the relationship between insular plant species richness and geographic factors of the islands. Kim et al. (2016) analysed insular floristic diversity at the South Sea of Jeollanamdo Province, South Korea and concluded that island biogeography equilibrium theory did not apply to insular flora of South Sea of South Korea.

Chapter 3. Methodology

3.1. Coleoptera sampling

Collecting work was done by two methods. The first is setting pitfall-traps. Trapping method receives high evaluation for collecting ground-dwelling arthropod species if researchers have enough time (average 36-48 hours) to get proper sample abundance. The bottom shape of trap container is circle with 8cm diameter or square with 8cm edges and the height length of the traps is also 8cm. These traps were buried flat with ground in each survey site to trap crawling beetles easily for 40 hours approximately. In some case that ground cannot be digged by shovel (e.g. shallow soil deposits), however, slope way made of soil and organic matter near the trap spot was established to let crawling beetles approach it.

In addition, attractant for beetles filled the traps for shortening collecting time. The attractant was made of 70ml of glacial acetic acid, 200ml of 99% ethyl alcohol, with reference to literatures. Quite naturally, there is high possibility of sampling biases if several species reacts to the attractant. However, most of brachypterous[①] or ground-dwelling species like the family of Carabidae, Staphylinidae and Tenebrionidae tend to react to acetic acid (Greenslade, 1964). The pitfall-traps were used mostly to collect them.

Relative to size and vegetation landscape diversity, five to eight survey sites were established per island. The survey sites

[①] The criterion that partitions brachypterous species and macropterous species is still debated, so in this paper, brachypterous species are defined as a species whose mean body length is under 10㎜ because the wing length of Coleoptera is related to its flight locomotion commonly and it tends to show direct proportion with its body length. At the same point of view, apterous species (i.e. Staphylinidae) and species that cannot fly are also regarded as brachypterous species in this paper.

represent dominant vegetation landscape characteristic of inter-islands and clearly divided one in intra-island. Setting traps for vegetation landscape could collect as much species that inhabit different environment of islands as possible, although small island size could attenuate effect of habitat difference of sampling species because of their locomotivity.

To collect beetles from various microhabitats, the second collecting method, "sweeping" using sweeping net was used. This method is a kind of hand-collecting and used mostly to collect several macropterous[②] and tree-dwelling species that researchers cannot collect by pitfall-traps. However, a plenty of abundance of brachypterous and ground-dwelling species was collected by sweeping. It was also carried out at many sites between 09:00 and 18:00 for four days per island. Trapped or swept beetles were kept in plastic vials filled with ethyl alcohol to prevent them decay and discoloration.

All research islands were visited twice from late June to early September, because general activity period of South Korean Coleoptera is known as a period from June to October (See Appendix 1).

② Because of the same reason in case of defining brachypterous species, macropterous species is defined as a species whose body length is more than 10mm in this paper.

3.2. Identification

All collected samples were kept in vials filled with ethyl alcohol and sent to physical geography laboratory of Seoul National University. Vials were kept 17℃ under refrigeration. Identification work proceeded, using guides, "National List of Species of Korea: Insect (Coleoptera Ⅰ)", "National List of Species of Korea: Insect (Coleoptera Ⅱ)", "Insect Fauna of Korea: Arthropoda: Insecta: Coleoptera" and "Pocket guide about Coleoptera".

Specific identification steps followed the key to the species, genera and families of superfamily described in "Insect Fauna of Korea: Arthropoda: Insecta: Coleoptera". It specifies shape, color, size of whole body, appendages and specific organ. Phylogenetic information of the samples is only family, genus, species. Other taxa such as superfamily or subgenus were omitted.

3.3. Data analysis

All identification result data were used to calculate several indices per island for comparison among islands. These indices were species richness index, dominance index, diversity index and similarity index.

Species richness is the number of different species represented in an ecological community, landscape or region. Measuring species richness is regarded as one of the measures of biodiversity. However, this measure is strongly dependent on sampling size and effort. Therefore, measuring species richness index has to account for this problem.

Among species richness indices, Margalef's species richness index is evaluated as a proper and simplest index dealing with the problem. It is calculated as follows:

$$\text{Margalef's Richness Index (MRI)} = \frac{S-1}{\ln N}$$

S = total number of species
N = total number of individuals in the sample
ln = natural logarithm

Dominance index shows ecological dominance of habitats of samples. Dominance is the degree to which a taxon is more numerous than its competitors in an ecological community, or makes up more of the biomass. That is, high dominance index means that a small number of species account for most of composition in abundance. The concept of dominance is useful to understand and estimate the environmental state of the community or landscape. Especially in most of plant or phytoplankton community researches, dominance index is calculated requisitely to produce basic

information of the research areas.

McNaughton's dominance index is generally used as a dominance index. Unlike Berger–Parker index that considers only the number of 1st dominant species as a variable, McNaughton's index calculates the sum of the two highest relative importance values in a sample. The index is calculated as follows:

$$\text{McNaughton's Dominance Index (MNDI)} = \frac{n_1 + n_2}{N}$$

n_1 = the number of individuals of the 1st dominant species
n_2 = the number of individuals of the 2nd dominant species
N = the total number of individuals in all the species

On the contrary, Berger–Parker index focuses on the only 1st dominant species. It is originally designed for measuring the dominant degree of phytoplankton. However, it applies to calculate dominance of other clades, especially that of fauna. The index is calculated as follows:

$$\text{Berger} - \text{Parker Dominance Index (BPDI)} = \frac{n_1}{N}$$

n_1 = the number of individuals of the 1st dominant species
N = the total number of individuals in all the species

Diversity index is similar with species richness at the point of considering the number of different species that are represented in a given community. However, diversity(species diversity) is

interpreted as a concept including species richness and species evenness. Species richness is a simple count of species, whereas species evenness quantifies how equal the abundances of the species are. That is, species diversity is representing the complexity of a community structure from the relation between the number of species and individuals. It is also the reason why difference between diversity index value and richness value occurs in researches.

Shannon-Wiener index has been a popular diversity index in the ecological literatures because it reflects a concept of the uncertainty through introducing the information theory. If a random sampling is conducted in a community with low species diversity, the sample species can be identified easily. However, if the work is conducted in a community with high species diversity, the sample species cannot be identified easily. Thus, high diversity means high uncertainty. Shannon-Wiener index is calculated as follow:

$$\text{Shannon} - \text{Wiener Diversity Index (SWDI)} = -\sum_{i=1}^{R} p_i \ln p_i$$

R = the total number of species
p_i = the proportion of individuals found in species .
ln = natural logarithm

Similarity index is presenting similarity of samples as numerical value. In this research, similarity means similarity of Coleoptera fauna between two islands. The degree of faunal similarities can be expressed by several indices. Especially, Nomura-Simpson's Coefficient (NSC) is estimated that it is appropriate for express similarities at the level of species taxon. NSC is calculated as follows:

$$\text{Nomura} - \text{Simpson's Coefficient(NSC)} = \frac{c}{b}, a > b, 1 \geq \text{NSC} \geq 0$$

a, b = the number of species occurring in the 1st and 2nd areas

c = the number of common species between a and b

Additionally, to apply several approaches to all data of South Korean insular Coleopteran species, nestedness calculator analysis was conducted. Nestedness is proposed by Hultén (1937; cited in Ulrich et al., 2009) to describe patterns of species composition within continental biotas and among isolated habitats such as islands and landscape fragments (Ulrich et al., 2009). That is, a nested pattern means that the species composition of small assemblages is a nested subset of the species composition of large assemblages.

Different mechanisms can cause a nested pattern of species occurrences. Most common seems to be a passive sampling (Cutler, 1991). Habitat isolation might also create nested subsets through dispersal limitation and selected immigration or extinction (Patterson & Atmar, 1986). Nested habitat types, disturbance regimes, and patterns of hierarchical niche overlap are supposed to create nested distributions (Kolasa, 1996; Patterson & Atmar, 2000).

Nestedness data are usually organized as a binary, presence(1)-absence(0) matrix. Each row is a species and each column is a site or a sampling time, and the entries indicated the presence or absence of a species in a site (Ulrich et al., 2009). In some studies, on the contrary to this, each row is a site or a sampling time and each column is a species (Gómez-Rodríguez et al., 2015).

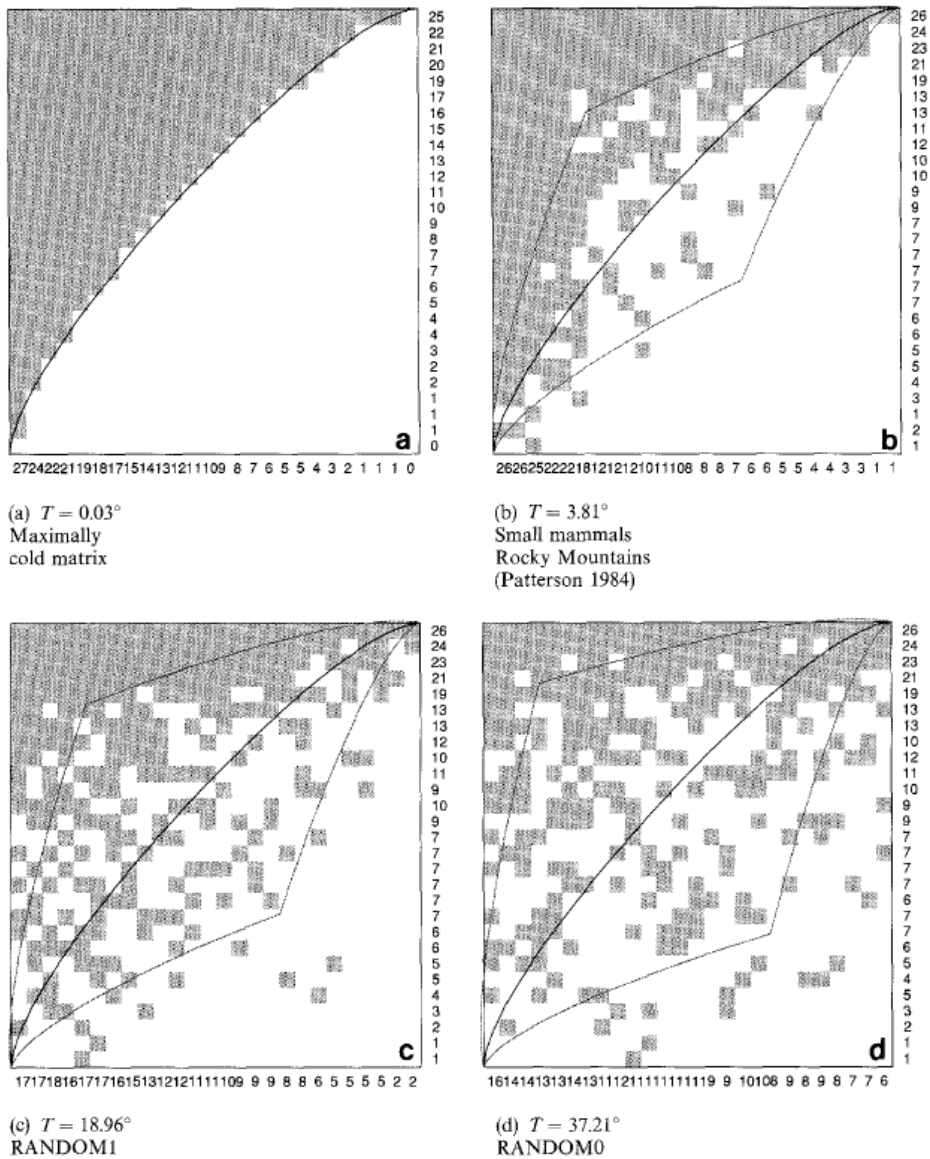

Figure 3. Biogeographic temperature. Four matrices are presented in increasing temperature sequence: (a) a maximally cold matrix, (b) actual data, (c),(d) matrices randomly filled under successively relaxed constraints (cited from Patterson & Atmar, 1993).

Nestedness can be measured by several measurements. Among them, measuring system' s temperature offered by Patterson & Atmar in 1993 is usually used. This measures the order in which species' extinctions would occur in the system. It uses an information approach to define the degree of ordering in a presence

absence matrix and defines a matrix temperature T in the range from 0 ° (perfect order) to 100 ° (perfect disorder). To calculate temperature, packing the matrix in a way that the packed matrix has a minimum temperature is necessary (Figure. 3a). Then the temperature T is computed as follows: First, a point [X,Y] is chosen that divides the matrix diagonal according to matrix fill (Figure. 3b). Second, an isocline that divides the whole matrix in two parts with upper part equaling the matrix fill and the lower part the unoccupied area is created (Figure. 3b). It is as in the following equation:

$$T = \frac{100}{0.04145}\frac{1}{SpSi}\left\{\sum_{i=1}^{Sp}\sum_{j=1}^{Si}\left(\frac{d_{ij}}{D_{ij}}\right)^2\right\}$$

Sp = the number of species

Si = the number of sites

d_{ij} = the distance of an empty cell [i:j] (unexpected absence) above the isocline or an occupied cell [i:j] (unexpected presence) below the isocline

D_{ij} = the total length of the diagonal through the focal cell [i:j]

0.04145 is approximately the maximum possible disorder of any given matrix. It is also possible to calculate so-called idiosyncratic temperatures for each species (T_{Sp}) and each site (T_{Si}). It measures the respective numbers of unexpected occurrences and absences. It is calculated as follows:

$$T_{Sp}(i) = \frac{100}{0.04145}\frac{1}{Si}\left\{\sum_{j=1}^{Si}\left(\frac{d_{ij}}{D_{ij}}\right)^2\right\}$$

and

$$T_{Si}(j) = \frac{100}{0.04145}\frac{1}{Sp}\left\{\sum_{i=1}^{Sp}\left(\frac{d_{ij}}{D_{ij}}\right)^2\right\}$$

Finally, whether T is significant and deviates from a temperature that would occur in a given matrix just by chance temperatures have to be compared with those obtained from an appropriate null model to assess it (Figure. 3c, 3d).

In this study, to analyze whether the assemblages of Coleoptera species showed nested structures among South Korean islands, I used *Nestedness* software to calculate nestedness temperature of data matrix (T), each species (T_{Sp}) and sites (T_{Si}). South Korean Insular Coleoptera data are collected and compiled from national natural environment surveys for uninhabited islands in Ministry of Environment of South Korea for uninhabited islands near Boryeong, Goheung, Gunsan, Taean, Tongyeong and Wando region (136 islands); from national natural environment surveys in Ministry of Environment of South Korea for inhabited islands that have been surveyed at least once (20 islands). Boreumdo, Gyodongdo, Janggodo and Yeonpyeongdo were excluded from the nestedness analysis because their specific composition of species was absent.

Species presence/absence of 421 species of 57 genera was recorded as a fitted matrix. All of these species presence were coded as '1' in my presence/absence matrix. The lack of documented presence in any islands was coded as '0'. However, the data can be modified in the future because they undergo continuous invasion of mainland individuals as aforementioned. Especially the small islands with short distance from the mainland are predicted to undergo replacement of its species. Null models were calculated by 1000 iterations and minimum distance was set up as 0.5.

The analysis was conducted twice to confine the effect of constraints of column (site) sequence. The island data were arranged by its geographical location. In specific, islands were given different site number along the coast line in turn first. In case that the number sequence of more than one island seems same, the closest island from the site with the latest number was selected as the next site. In this way, all islands were given site number by sequence from Baekryeongdo (North-West) to Ulleungdo (North-East). The first analysis was conducted with no constraints on the columns and the second one was conducted with sequence constraints on the columns.

Chapter 4. Research Results and Analysis

4.1. Identification Results

Collected samples are 772 samples from 24 species. Pitfall traps also collected a number of small individuals estimated as pomace flies, ants, true bug and spiders, but they are all removed for beetle sampling.

The difference of vegetation landscape shows a little difference of abundance between survey spots in the same island. However, it is limited to specific species like Gonocephalum pubens that needs special habitats (seaside sand). And because of their locomotivity and small island size, definite difference of abundance did not occur between survey spots.

Because some collected individuals are larvae mode or not recorded in the guides, they were not identified as level of species taxon. For example, most of collected Staphylinidae genera were larvae mode. The guides do not clarify identification criteria about shape information of Staphylinidae larvae. However, the primary morphological characteristics that most of Staphylinidae larvae have in common were observed clearly. It is estimated that their activity period of imago is late than one of other taxonomic groups. Staphylinidae samples were, therefore, recorded as Staphylinidae genus A, B, C. Silphidae genus A, Gyrinidae genus A, *Necydalis* species A, Chrysomelidae genus A, Elateridae genus A were also recorded in the same way.

Although the island distance of dozens of kilometers from mainland seems far to Coleoptera, the island communities are estimated that they exchange their genes with external individuals consistently. Because the unique traits of samples were not clear when compared to the morphological information of mainland species.

4.1.1. Sapsido

In Sapsido, 6 species of 6 genera of 5 families (129 individuals) were collected. Most collected group was *Oomorphoides cupreatus* (54 individuals), brachypterous and having distinguishing habitat preference (several genera of Araliaceae), followed by *Gyrinus japonicus*, *Brachinus scotomedes*, Staphylinidae genera A · B and *Harmonia axyridis*. Clades collected only in Sapsido were two genera of Staphylinidae.

Suborder	Family	Genus	Species	#
Adephaga	Carabidae	*Brachinus*	*scotomedes*	14
Adephaga	Gyrinidae	*Gyrinus*	*japonicus*	27
Polyphaga	Chrysomelidae	*Oomorphoides*	*cupreatus*	54
Polyphaga	Coccinellidae	*Harmonia*	*axyridis*	8
Polyphaga	Staphylinidae	A		11
Polyphaga	Staphylinidae	B		15

Table 2. Identification Result of Sapsido

4.1.2. Hodo

Hodo shows 11 species of 10 genera of 9 families (211 individuals). *Gonocephalum pubens* was most collected species (68 individuals), followed by *Aulacophora nigripennis*, *Selatosomus puncticollis*, *Oomorphoides cupreatus, Colasposoma dauricum*, Staphylinidae genus C, *Harmonia axyridis, Cychrus koltzei*, Silphidae genus A and *Metabolus impressifrons*. Clades collected only in Hodo were 6 species (*Cychrus koltzei*, *Colasposoma dauricum, Selatosomus puncticollis, Metabolus impressifrons*, Silphidae genus A and *Gonocephalum pubens*).

Suborder	Family	Genus	Species	#
Adephaga	Carabidae	*Cychrus*	*koltzei*	10
Polyphaga	Cerambycidae	*Megopis*	*sinica*	9
Polyphaga	Chrysomelidae	*Colasposoma*	*dauricum*	14
Polyphaga	Chrysomelidae	*Aulacophora*	*nigripennis*	38
Polyphaga	Chrysomelidae	*Oomorphoides*	*cupreatus*	15
Polyphaga	Coccinellidae	*Harmonia*	*axyridis*	11
Polyphaga	Elateridae	*Selatosomus*	*puncticollis*	22
Polyphaga	Scarabaeidae	*Metabolus*	*impressifrons*	3
Polyphaga	Silphidae	A		7
Polyphaga	Staphylinidae	C		14
Polyphaga	Tenebrionidae	*Gonocephalum*	*pubens*	68

Table 3. Identification Result of Hodo

4.1.3. Nokdo

11 species of 11 genera of 9 families were identified at Nokdo (233 individuals), which is same with them of Hodo. Most collected group was *Aulacophora nigripennis* (72 individuals), followed by *Gyrinus japonicus*, Chrysomelidae genus A, Gyrinidae genus A, *Protaetia mandschuriensis, Necrophila jakowlewi, Chalcophora japonica, Necydalis* species A, *Brachinus scotomedes*, Staphylinidae genus C and *Harmonia axyridis*. Clades collected only in Nokdo were 5 species (Gyrinidae genus A, *Chalcophora japonica, Necydalis* species A, Chrysomelidae genus A and *Protaetia mandschuriensis*).

Suborder	Family	Genus	Species	#
Adephaga	Carabidae	*Brachinus*	*scotomedes*	13
Adephaga	Gyrinidae	*Gyrinus*	*japonicus*	26
Adephaga	Gyrinidae	A		20
Polyphaga	Buprestidae	*Chalcophora*	*japonica*	15
Polyphaga	Cerambycidae	*Necydalis*	A	15
Polyphaga	Chrysomelidae	*Aulacophora*	*nigripennis*	72
Polyphaga	Chrysomelidae	A		25
Polyphaga	Coccinellidae	*Harmonia*	*axyridis*	2
Polyphaga	Scarabaeidae	*Protaetia*	*mandschuriensis*	19
Polyphaga	Silphidae	*Necrophila*	*jakowlewi*	18
Polyphaga	Staphylinidae	C		8

Table 4. Identification Result of Nokdo

4.1.4. Oeyeondo

In Oeyeondo, 8 species of 7 genera of 6 families were collected (182 individuals). Most collected group in Oeyeondo was *Chrysolina aurichalcea* (49 individuals), followed by *Holotrichia diomphalia, Harmonia axyridis, Holotrichia parallela, Popillia mutans, Megopis sinica, Necrophila jakowlewi* and Elateridae genus A. Clades collected only in Oeyeondo were 4 species (*Chrysolina aurichalcea, Holotrichia diomphalia, Holotrichia parallela, Popillia mutans*).

Suborder	Family	Genus	Species	#
Polyphaga	Cerambycidae	*Megopis*	*sinica*	13
Polyphaga	Chrysomelidae	*Chrysolina*	*aurichalcea*	49
Polyphaga	Coccinellidae	*Harmonia*	*axyridis*	24
Polyphaga	Elateridae	A		20
Polyphaga	Scarabaeidae	*Holotrichia*	*diomphalia*	26
Polyphaga	Scarabaeidae	*Holotrichia*	*parallela*	20
Polyphaga	Scarabaeidae	*Popillia*	*mutans*	18
Polyphaga	Silphidae	*Necrophila*	*jakowlewi*	12

Table 5. Identification Result of Oeyeondo

4.2. Ecological indices results

Calculated ecological indices for all islands were presented as table 7 and 8. In richness index, Hodo recorded the highest value (1.835). Nokdo follows Hodo, but the difference between the index values of two islands is only about 0.034. The values of Oeyeondo and Sapsido recorded 3rd and 4th.

In McNaughton's dominance index, Sapsido recorded the highest value (0.628), which means that individuals of 1st and 2nd dominant species accounts for more than 60% of all samples in Sapsido. Hodo also shows that two species account for its all population of Coleoptera (0.502). Nokdo and Oeyeondo recorded 3rd and 4th. Sapsido also recorded highest value in Berger-Parker dominance index (0.419). The ranks of other islands are same with that of McNaughton's index.

Unlike the result of richness index, diversity index result shows that index value of Nokdo is highest (2.131), followed as Hodo, Oeyeondo and Sapsido. The difference between the index values of Hodo and Nokdo is about 0.067, which is a small difference compared with Hodo-Oeyeondo (0.084) and Oeyeondo-Sapsido (0.415).

Island	MRI	MNDI	BPDI	SWDI
Sapsido	1.029	0.628	0.419	1.565
Hodo	1.869	0.502	0.322	2.064
Nokdo	1.835	0.421	0.309	2.131
Oeyeondo	1.345	0.412	0.269	1.980

Table 6. Indices of Richness, Dominance and Diversity for the Islands. MRI = Margalef's Richness Index, MNDI = McNaughton's Dominance Index, BPDI = Berger-Parker Dominance Index, SWDI = Shannon-Wiener Diversity Index

To calculate similarity index, common species were found after the identification work. Common species between Sapsido and Hodo are *Oomorphoides cupreatus* and *Harmonia axyridis*. Those between Sapsido and Nokdo are *Gyrinus japonicus* and *Harmonia axyridis*. Those between Hodo and Nokdo are *Aulacophora nigripennis*, *Harmonia axyridis* and Staphylinidae genus C. Those between Hodo and Oeyeondo are *Megopis sinica* and *Harmonia axyridis*. That between Nokdo and Oeyeondo is *Harmonia axyridis*.

On the calculated similarity index, Hodo-Nokdo recorded the highest value (0.273), followed as Sapsido-Hodo, Sapsido-Nokdo, Hodo-Oeyeondo (0.182) and Nokdo-Oeyeondo (0.090) except zero values. Oeyeondo recorded zero value when calculated only with Sapsido.

Inter Islands	Common species	NSC
Sapsido - Hodo	2	0.182
Sapsido - Nokdo	2	0.182
Sapsido - Oeyeondo	0	0
Hodo - Nokdo	3	0.273
Hodo - Oeyeondo	2	0.182
Nokdo - Oeyeondo	1	0.090

Table 7. Similarity Index between the Islands. NSC = Nomura-Simpson's Coefficient

4.3. Nestedness temperature results

The nestedness temperature of matrix (T) species (T_{Sp}), and sites (T_{Si}) were generally low. T was 1.80 °, and T_{Si} of most islands (125 of 156) recorded value under 3.06 °, which is low 95% confidence level. This bias is also confined in skewness value which also recorded 0.14 (Table. 9). The significantly colder sites (whose temperature is under 3.06 °) were composed of 124 uninhabited islands and 15 inhabited islands (see Appendix 2). The coldest three sites were Hangdo (0), Daeryongdo (0.01) and Bakseom (0.01). Among the coldest species in T_{Sp} values, peculiarly, 33 species recorded zero value. The hottest three species were fk(*Chalcophora japonica*), ad(*Cicindela gemmata*) and qc(*Rhizopertha dominica*) species (see Appendix 3).

The difference between results of matrix with no constraint and sequence-constraint on columns was not significant with all temperature values T, T_{Sp}, T_{Si}.

Species	Sites	MatFill	MatTemp	SimTemp
421	156	0.02	1.80	3.29
StdDev	Z-score	Skewness	L95%Conf	U95%Conf
0.12	-12.04	0.14	3.06	3.55

Table 8. Nestedness Temperature Result of the Presence/Absence Matrix of South Korean Insular Coleoptera Species

Chapter 5. Discussion

5.1. Distributional Characteristics of South Korean Insular Coleopteran species

Based on South Korean Coleoptera data mentioned in Chapter 3, correlation between the classical island biogeography factors (island size and island distance from mainland) and the number of species is showed in Figure 4 and 5. Island size seems strongly associated with species diversity (Figure. 4). The correlation coefficient was 0.728 and p value was under 0.001. Figure 5 also shows two clearly divided clusters with different rates of increase (See Appendix 5). The rate of increase of cluster whose logged IS value is under zero seems positive ($y=6.42+0.62x$). However, that of cluster whose logged IS value is above zero seems negative ($y=49.54-4.97x$). These big islands are all inhabited islands. Therefore, the relationship between island size and the number of species seems positive generally. At the same time, however, big size also means that the island can support more human. Severe and continuous human activities may affect low diversity of Coleopteran groups, although the cause of change of the increase rate cannot be affirmed by the graph exactly.

On the other hand, distance cannot be a main factor of general species diversity (Figure. 5). The correlation coefficient was 0.264 and p value was under 0.01, showing the opposite tendency comparing to the negative relationship between species diversity and island distance. This may be originated from the correlation between explanatory variables (Island size and Island distance from mainland; correlation value=0.437; $p-value<0.001$) (See Appendix 4). Thus, distribution of surveyed islands is biased. Therefore, to erase problem of multicolinearity, a ridge regression analysis was conducted additionally three times; first is for the number of total species and explanatory variables, and second is for the number of

brachypterous species and explanatory variables, and the last is for the number of macropterous species and explanatory variables. However, for all three cases, fittest model cannot be found.

It may mean that Coleoptera species often disperse to the islands in any way despite of its dispersal limitation. The fact that the morphological traits of samples had no significant difference with those of the mainland also indicates it. However, the dispersal mode is unclear. In case of uninhabited islands that ferries do not visit, seasonal wind or typhoon is available for Coleoptera to disperse.

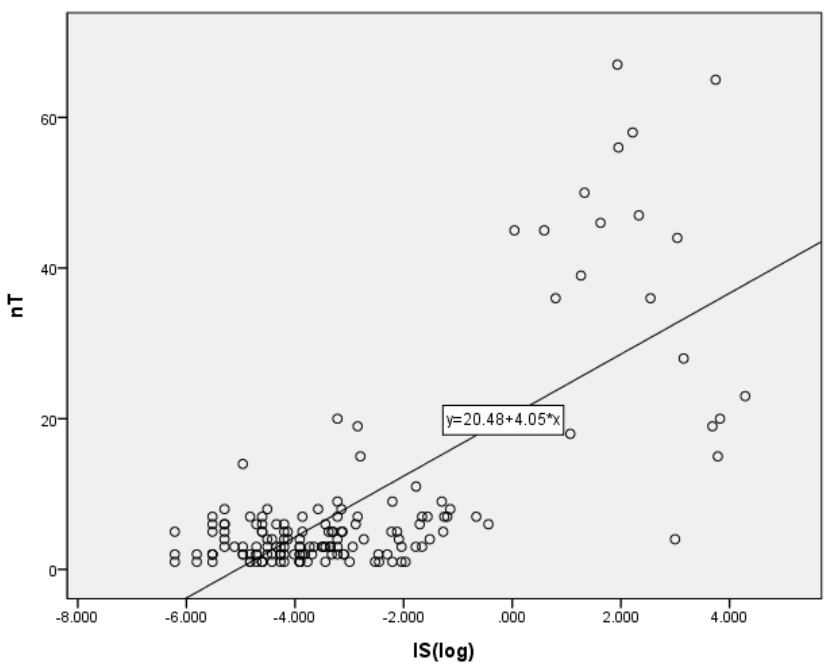

Figure 4. Correlation analysis between logged Island size (IS) and the number of Coleoptera species (nT) in South Korea (Fitted regression equation: y=20.48+ 4.05x, R^2=0.529).

From the nestedness temperature analysis, both two interpretations of T_{Sp} and T_{Si} can be tried. The combination of sorted T_{Sp} values can create a sort of zones. T_{Si} can be applied and associated with the relationship that the difference between wing length presented in Chapter 4.

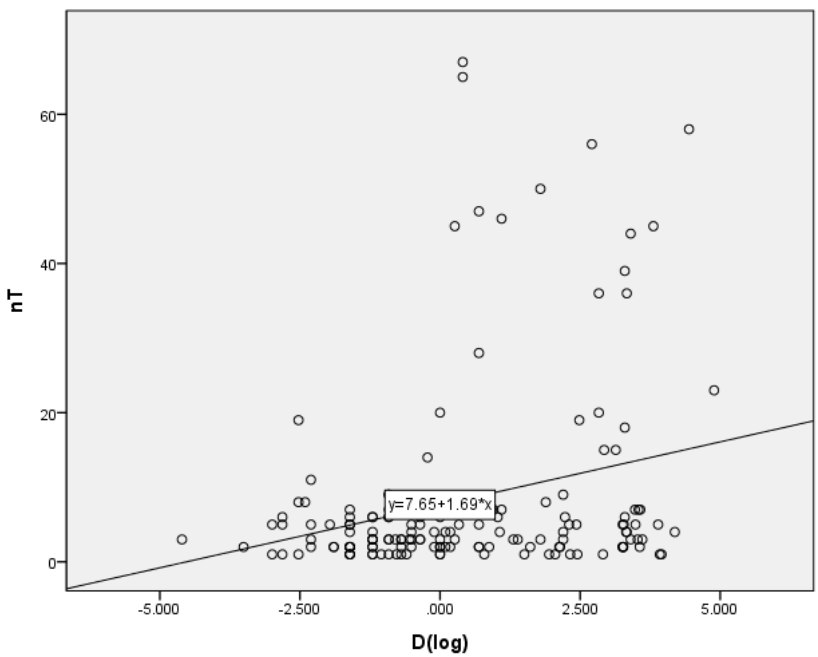

Figure 5. Correlation analysis between logged Island distance (D, ㎞) from the mainland and the number of Coleoptera species in South Korea (Fitted regression equation: y=7.65+ 1.69x, R^2=0.069).

5.1.1. Insular Coleopteran zones in South Korea

The T_{Sp} result shows several species with frequent presence and low temperature such as ga (*Coccinella septempunctata*), gf (*Henosepilachna vigintioctomaculata*), jr (*Aulacophora nigripennis*) and jo (*Basilepta fulvipes*) (See Appendix 3). These species, especially species whose temperature is under 0.2 can be interpreted as widespread but strongly nested species. Therefore, new zones can be set up based on the nestedness temperature data and presence/absence data (Figure. 8). The cold temperature species map shows 5 temperature zones. Although data covers most of South Korean coast regions except southwestern region (Shinan, Mokpo, Jindo and Haenam), the main habitat islands of cold temperature species are located in the West coast.

Each cold zone is characterized by its type species. All type species are not apterous, but significant difference between the ratio of brachypterous and macropterous species in the cold zones is not identified (5 brachypterous species and 3 macropterous species). Nevertheless, this map shows several distributional characters of South Korean insular Coleoptera species.

First, West Coast zone is predicted to reach Wando-Goheung zone. *Aulacophora nigripennis* and *Coccinella septempunctata* are type species of both West Coast zone and Wando-Goheung zone. Considering their low temperature and geographical continuity, there is high probability of existence of many islands colonized by them in No data zone. *Aulacophora nigripennis* and Coccinellidae species such as *Coccinella septempunctata* showed their chance of widespread dispersal in Sapsido, Hodo, Nokdo and Oeyeondo (Table 2, 3, 4, 5, Figure. 4).

Second, the West coast of South Korea (West Coast zone, Incheon-Seosan zone, Taean-Boryeong zone and Taean-Gunsan zone) has more cold temperature species and complex overlapped regions. On the contrary, South coast shows few cold temperature species and most of them are also nested species in the West coast.

Therefore, a mechanism especially associated with dispersal may disturb the nested pattern in the South coast. There is also high probability that spatial turnover of species is more important mechanism that explains the distributional pattern of the South coast. In this point of view, Wando–Goheung zone can be regarded as a marginal region of which the nested–resultant distribution can be found. If the degree of selecting type species becomes more moderate, then the marginal line between the regions that different patterns drive may be clear. For example, apterous species was not selected as cold temperature species because of their limitation of dispersal to islands and biased dispersal mode such as ferry visits, but a few apterous species can be type species of newly selected cold zones in a moderate total presence limitation. And it may show new and clear distributional pattern of South Korean Coleoptera.

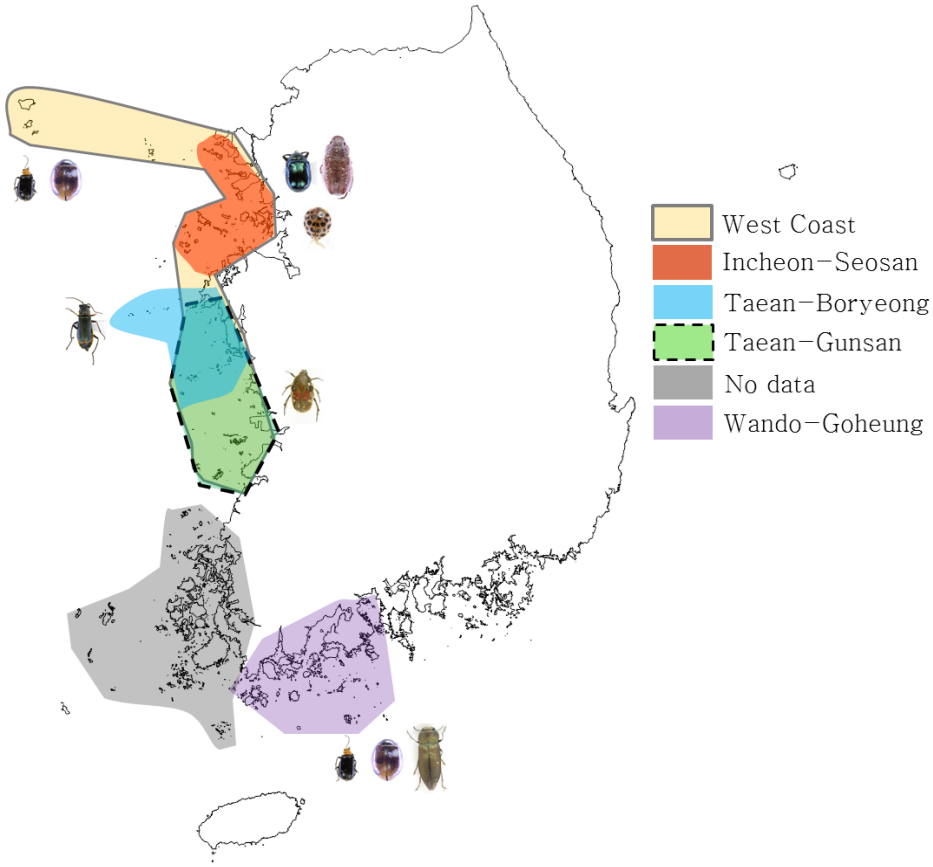

Figure 6. Cold temperature species map (T_{Sp}<0.2, total presence>10). Different zones are originated from different species and marked by different colors; yellow shade: West Coast (type species: *Aulacophora nigripennis* and *Coccinella septempunctata*); red shade: Incheon-Seosan (type species: *Adoretus tenuimaculatus, Basilepta fulvipes* and *Henosepilachna vigintioctomaculata*) blue shade: Taean-Boryeong (type species: *Malachius prolongatus*); green shade: Taean-Gunsan (type species: *Cetonia pilifera*); grey shade: No data region; violet shade: Wando-Goheung (*Aulacophora nigripennis, Coccinella septempunctata* and *Anthaxia proteus*). All pictures of type species are cited from Korea National Arboretum.

5.1.2. Relationship between nested pattern and wing length of Coleoptera

Not only T_{Sp} but also T_{Si} gives other distributional information about South Korean Coleoptera species. As mentioned earlier, ridge regression analysis did not fit any models when all data are considered. However, the effect of island distance is significant among the macropterous species in strongly-nested (site temperature is under 3.06° , corresponding to fraction out of low 95% confidence level) sites (Table. 10). N is 125 sites that reflect the fraction. Most of lowest temperature sites were uninhabited islands. From the site whose T_{Si} was lowest to the site whose T_{Si} was 80^{th} lowest, only four inhabited islands were included. This suggests that human disturbances affect the nested pattern negatively. Nevertheless, inhabited island data among strongly-nested sites are also included in this analysis. Originally, inhabited island data should be excluded to erase human disturbance on the data. If so, however, the number of islands (N) becomes too small.

Among the significant values, the correlation between nMac and D is remarkable (0.415). As mentioned above, macropterous-widespread species colonize and disperse more slowly in regional distribution than brachypterous-restricted and brachypterous-widespread species. The correlation value between nMac and D seems valid for accounting for the character of macropterous species. Macropterous species can spread and reach the remote site in comparison with brachypterous species. Therefore, they may rather colonize better in the remote islands by avoiding competition with other settler groups, although long distance is a great barrier to them. Thus, the relationship between nMac and D comes from the difference between the locomotivity of brachypterous and macropterous species. nBra was a significant variable in other cases, but not identified as a significant value in the strongly-nested sites (p-value=0.093 with IS; 0.818 with D). Nevertheless, nBa and rBra value should not be ignored because they implicates a chance of

relationship with the island distance in the other environments (i.e. uninhabited islands).

		IS	D	nMac	nBra	nT	rMac	rBra
IS	Pearson		.278*	.339**	.211	.323**	.071	-.070
	p-value		.026	.006	.093	.009	.576	.585
	N		125	125	125	125	125	125
D	Pearson	.278*		.415*	-.029	.106	.216	-.216
	p-value	.026		.016	.818	.404	.087	.087
	N	125		125	125	125	125	125
nMac	Pearson	.339**	.415*		.168	.576**	.484**	-.482**
	p-value	.006	.016		.184	.000	.000	.000
	N	125	125		125	125	125	125
nBra	Pearson	.211	-.029	.168		.903**	-.719**	.721**
	p-value	.093	.818	.184		.000	.000	.000
	N	125	125	125		125	125	125
nT	Pearson	.323**	.106	.576**	.903**		-.385**	.388**
	p-value	.009	.404	.000	.000		.002	.002
	N	125	125	125	125		125	125
rMac	Pearson	.071	.216	.484**	-.719**	-.385**		
	p-value	.576	.087	.000	.000	.002		
	N	125	125	125	125	125		
rBra	Pearson	-.070	-.216	-.482**	.721**	.388**		
	p-value	.585	.087	.000	.000	.002		
	N	125	125	125	125	125		

Table 9. Correlation Result among Island Size (IS; logged), Island Distance (D; logged), the Number of Macropterous Species (nMac),and Brachypterous Species (nBra) and Total Species (nT), and the Component Ratio of Macropterous species (rMac; calculated as nMac / nT) and Brachypterous Species (rBra; calculated as nBra / nT). '*' means that correlation is significant at 0.05 level. '**' means that correlation is significant at 0.01 level.

5.2. The Characters of Insular Coleopteran Communities of Study Area

5.2.1. Interpreting Composition of Species

Identification result reflects environment of Sapsido well. The dominant species, *Oomorphoides cupreatus* indicates that Araliaceae group inhabits in Sapsido. However, it is thought that *Oomorphoides cupreatus* may prefer middle-aged larch plantation in another research (Ohsawa & Nagaike, 2006). The second dominant species, *Gyrinus japonicus* also indicates fresh water environment of Sapsido. This group is speculated that was trapped in the way to other ponds. Over the left, these species have adapted to Sapsido as a result.

Despite its big area and short distance from mainland, only 8 species were collected in Sapsido. This means that other factors affect its species richness and composition stronger than classical island biogeography theory. However, it is remarkable for the fact that all species in Sapsido have poor locomotivity; *Brachinus scotomedes* cannot fly, and other species are small and brachypterous. Generally, regional distributions are wider in brachypterous-restricted and brachypterous-widespread species than macropterous-widespread species (Gutiérrez et al., 1997). Sapsido species may be explained by the general law.

Nonetheless, it seems that island size and distance from mainland did not affect the number of Sapsido species significantly. The reason for this can be explained as two sides. First, big island size and short distance from mainland give immigration chance to all species including Coleoptera. Survey of natural environment of Sapsido in 2009 shows various fauna practically: fish (3 families, 3 species), amphibian (3 families, 4 species), reptile (3 families, 5 species), terrestrial insect (8 orders, 76 families, 180 species), benthic invertebrates (2 phylum, 2 classes, 7 orders, 14 families, 22 species) and bird (53 species). This is a distinctive difference

from other islands. Thus, predators or competitors may have kept the number of Coleoptera species down. This perspective has the same view that emphasizes importance of prey–competition and the number of predators (Buckley & Jetz, 2007).

Second, human disturbance could keep the number of Coleoptera species down. Human disturbances that Sapsido undergoes get organized as follows. Sapsido is famous for its beach and coastal walk in Chungcheongnamdo province, which causes a lot of tourism demand through 4 seasons. In accordance, paved roads are built for tourists' convenience and shuttle ferry with people and cars runs 3 times in a day. This leads to building architecture structures, such as new accommodations. Therefore, Coleoptera species vulnerable to habitat loss and introduction of invasive species by tourists could have not colonized successfully and become extinct, although moderate disturbance can diversify the fauna of the region.

Hodo presents *Gonocephalum pubens* and *Aulacophora nigripennis* as 1st and 2nd dominant species. *Gonocephalum pubens* is arenicolous species, and is linked closely with widespread sandy soil and sand dune of Hodo. So it is observed well near private houses as well as the sand dune. *Aulacophora nigripennis* forms strong association with Cucurbitaceae species (cucumber and watermelon) and legume. Because dominant plant species of Hodo is pinaceous, *Aulacophora nigripennis* is conjectured that it usually nibbles the crop species (leaves of legume and Cucurbitaceae species). Chrysomelidae species including *Aulacophora nigripennis* of Hodo are diverse and the sum of individuals is 67, similar with the number of *Gonocephalum pubens*. It implies that vegetation of Hodo is favorable for Chrysomelidae group, although *Gonocephalum pubens* is dominant because of widespread sand.

Compared with Nokdo and Oeyeondo, Hodo seems affected by the distance from mainland than Sapsido. Its number of species is same with that of Nokdo, and more than that of Oeyeondo. And also different from Sapsido, several macropterous species (*Megopis*

sinica and Metabolus impressifrons) are observed in Hodo. Although species with low locomotivity can reach Hodo through islands between Sapsido and Hodo used as stepping stones, macropterous species have an advantage of reaching. Megopis sinica could colonize in Hodo because its larvae prey on pine tree, the dominant plant in Hodo.

Nokdo also presents 11 species, and the dominant species is *Aulacophora nigripennis*. It seems similar with Hodo, but the composition of species is different from that of Hodo. The environment of Nokdo is explained as very favorable habitat for *Aulacophora nigripennis* because the difference between 1st dominant species and 2nd dominant species is bigger than that of Hodo. In Hodo, *Gonocephalum pubens* dominate the area, associated with sand dune ecosystem. However, in habitat with similar vegetation but without sand soil, Nokdo, *Aulacophora nigripennis* dominate Coleoptera abundance.

Like the preceding, the number of species in Nokdo implies the effect of the distance from mainland. Macropterous species are three (*Chalcophora japonica, Necydalis* species A, *Protaetia mandschuriensis*). *Chalcophora japonica* is only one Buprestidae species collected in this research. This species needs pine tree like the case of *Megopis sinica* in Hodo. They may be in the same ecological niche in each island. *Necydalis* species A also forms community on dead trees generally. Therefore, it is expected that *Necydalis* species A inhabits dominant pine forest.

Chrysolina aurichalcea and *Holotrichia diomphalia* are 1st and 2nd dominant species among 8 species collected in Oeyeondo. *Chrysolina aurichalcea* have reached and colonized despite of low locomotivity as a brachypterous Chrysomelidae species. Its migration route and reach mode are veiled, but it verifies the preceding theory that regional distributions are wider in brachypterous-restricted and brachypterous-widespread species than macropterous-widespread species as 1st dominant species. Nevertheless, 53㎞ of the distance from mainland is so long that

brachypterous species cannot reach Oeyeondo by their own locomotivity. 2nd dominant species in Oeyeondo, *Holotrichia diomphalia* is one genus of Scarabaeidae family, typical macropterous species. Other Scarabaeidae species in Oeyeondo recorded similar number of individuals. As a result, the number of macropterous species and individuals come to 4 of 8 species and 77 of 182 individuals, which is the highest rate among four islands. In this point of view, the effect of the distance from mainland is conjectured as an important factor affecting Coleoptera communities of the islands clearly.

In the point of insular species, Silphidae family was not observed only in. It can be interpreted that Silphidae group is sensitive to human disturbances and invasive species in the relationship with predators or competitors in same ecological niche, and that dispersal ability of Silphidae group is poor.

Chrysomelidae group dominated Coleoptera communities of four islands (Sapsido, Hodo, Nokdo, Oeyeondo) despite of its low locomotivity. Noticed that these four islands are inhabited islands, migration mode and colonization of Chrysomelidae group seems affected by human disturbance clearly. Once it has colonized in the islands, it adapts to the vegetation of them and disperse widely in the region.

Harmonia axyridis is also observed in the four islands. However, it does not dominate Coleoptera communities anywhere. Although *Harmonia axyridis* can adapt to various habitats (Brown et al., 2011), it seems that there is a mechanism that control the abundance of *Harmonia axyridis*. Its rate to Coleoptera community rises in Oeyeondo. Therefore, there is a possibility that carnivorous Carabidae group preys on *Harmonia axyridis*.

5.2.2. Interpreting Ecological Indices

Two dominance indices (MNDI and BPDI) seems in the relationship with the distance from mainland or the number of ferry visits per island. If the distance increases, MNDI and BPDI decrease in accordance. It provides two suggestion: First, in the classical island biogeography theory, short distance from mainland means that immigration rate of species with low locomotivity can be high. Especially, as previously described above, brachypterous group disperse widely in a restricted area if they immigrate to islands successfully. As time passes, the composition of Coleoptera community will be dominated by species such as Chrysomelidae group as a result. On the other hand, regardless of existence of brachypterous group, macropterous group does not colonize full in any regions (Figure. 4). Second, considering human disturbance, more frequent ferry visits increases the possibility of introduction of invasive species from mainland or other islands. Frequent ferry visits can be misunderstood that they are same as the large number of visitors themselves. However, the number of visitors to Nokdo is smaller than to Oeyeondo, although the number of ferry visits to Nokdo is larger than to Oeyeondo (Table. 1). Therefore, human disturbance affecting dominance index of islands is understood as the point of invasive species, rather than the point of visitors' several type of disturbances.

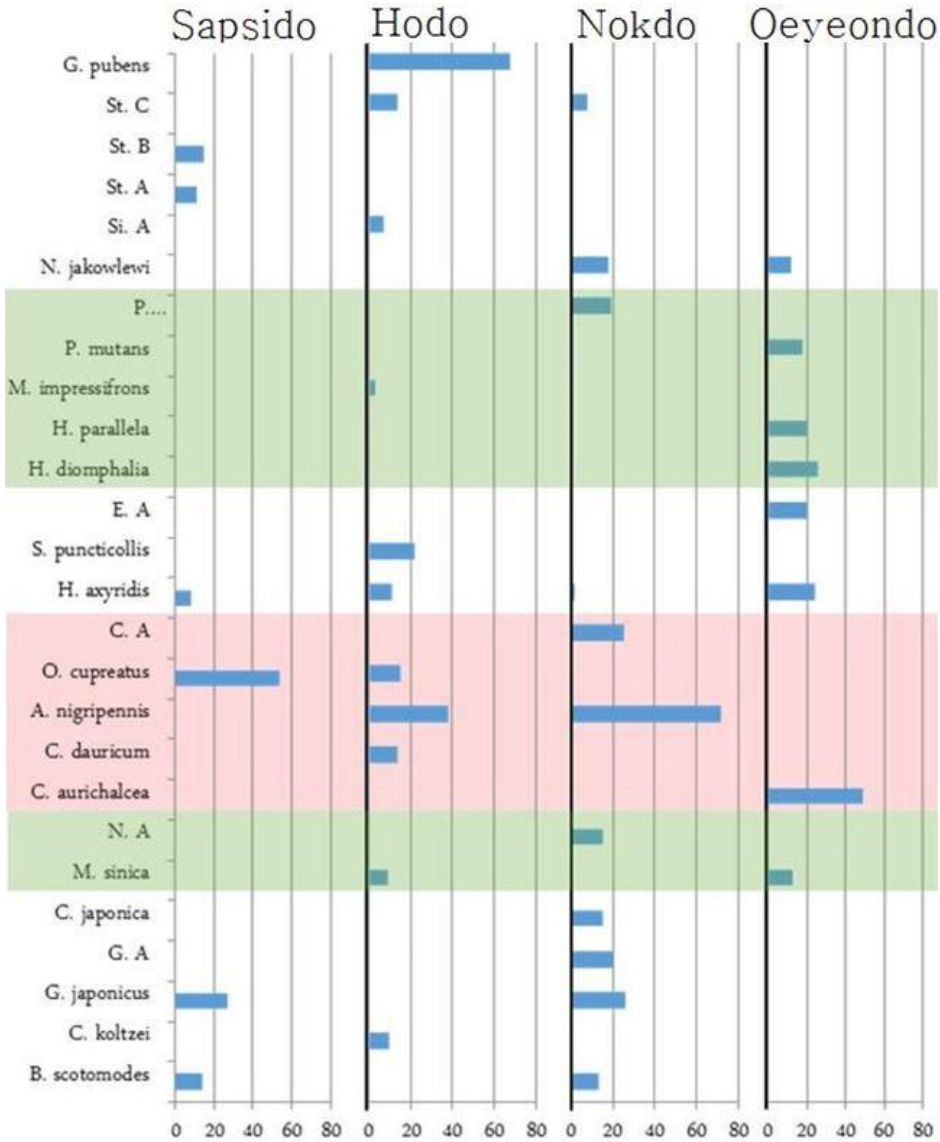

Figure 7. The number of sampled individuals for each island. X-axis is the number of samples, Y-axis is the name of samples. Green shade covers macropterous species (*Protaetia mandschuriensis, Popilla mutans, Metabolus impressifrons, Holotrichia parallela, Holotrichia diomphalia, Necydalis A and Megopis sinica*). Red shade covers Chrysomelidae species (Chrysomelidae *A, Oomorphoides cupreatus, Aulacophora nigripennis, Cholasposoma dauricum and Chrysolina aurichalcea*)

MRI and SWDI is hard to interpret consistently, with single factor. Nevertheless, it is remarkable that the bigger the island size, the smaller SWDI value. It is the opposite result to the classical

island biogeography theory. Thus, it has to be understood in the point of human disturbance. Island size is in accordance with human population in the data. MRI seems affected by the factors of classical island biogeography theory and human disturbance multiply, and that it needs additional research to measure the clear effect of each factor.

NSC results give significant interpretation. NSC value representing zero is recorded when it comes to measuring two islands in relatively long distance: Sapsido-Oeyeondo. This fact suggests that the composition of Coleoptera community of islands changes as distance from mainland or stepping stones increases, which may result from two factors, the locomotivity difference between brachypterous group and macropterous group, and human disturbance affecting through several types per island.

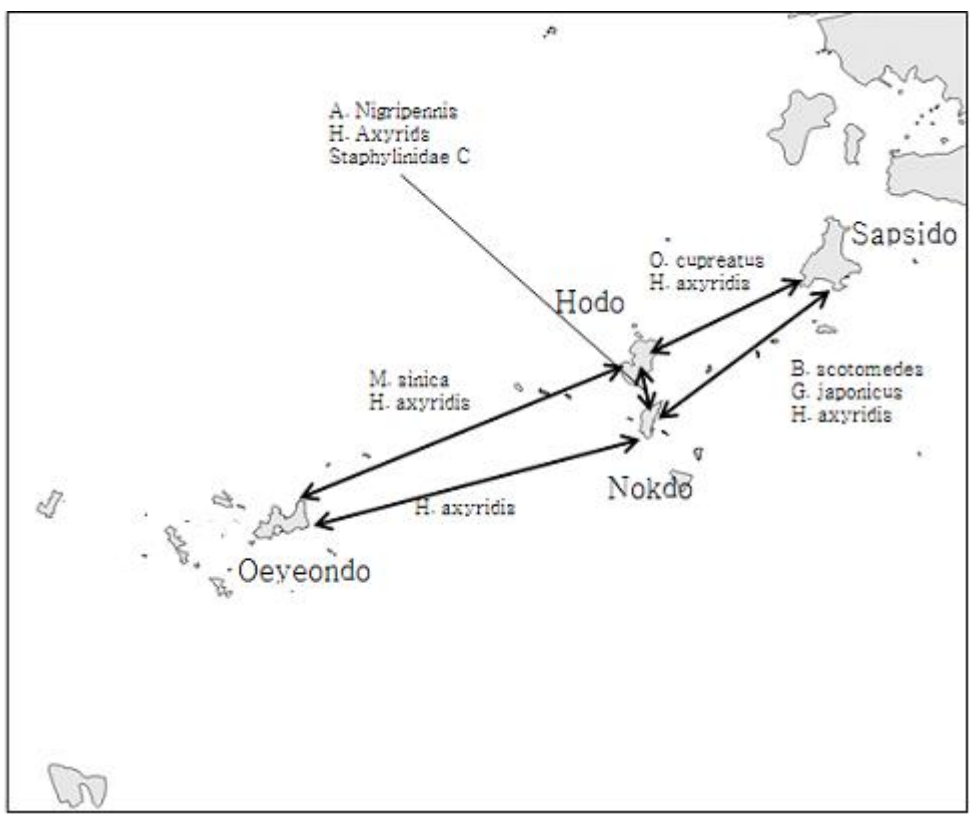

Figure 8. Common species among each island

Chapter 6. Conclusion

In this study, I identified Coleoptera communities in Sapsido, Hodo, Nokdo and Oeyeondo, and found several factors affecting Coleoptera communities of the west coastal islands in South Korea. Because of characteristics of the islands that have undergone human disturbances historically, island size seems that it does not matter in understanding and predicting the characteristic of insular Coleoptera communities. Instead of it, distance between the island and mainland is evaluated with high importance to predict the composition of species. Human disturbance such as the number of ferry visits, agriculture have possibilities that affect the community, but real dispersal mode of Coleoptera with low locomotivity has to be studied in the future.

Through comparing ecological indices and taxonomic traits among four islands, the locomotivity associated with the wing length seems a key mechanism that affects dispersal of Coleoptera groups. To apply this concept and assess whether island distance differentiates species composition of the island, additional analyses such as nestedness analysis, ridge regression analysis and correlation analysis were conducted.

The nestedness analysis result, especially nestedness temperature result shows the high nestedness of islands in South Korea. Most of the cold temperature species are distributed along the West Coastal islands. It suggests that the West coastal islands of South Korea are more nested in terms of the distribution than the Southeast coastal islands relatively. Coccinellidae groups and several Chrysomelidae groups (i.e. *Aulacophora nigripennis*) are nested along the West and South coastal islands of South Korea. It is worth researching their characters of dispersal and colonization in the future.

Contrary to the result about the four islands, all South Korean islands data shows the significant positive relationship between the island size and the number of species. It is consistent with both

brachypterous species and macropterous species. In contrast, contrary to correlation analysis result with all South Korean islands data, difference of wing length and consequential difference of locomotivity may affect distributional pattern in the nested regions. Macropterous species seems to colonize better in the remote islands. However, correlation analysis for the weakly-nested regions tends to show adverse results that only distribution of brachypterous species is correlated with the distance. In stable equilibrium-like ecological structure such as strongly-nested regions, therefore, dispersal ability associated with their flightness can be regarded as an important factor to understand the tendency of formation of South Korean insular Coleoptera communities.

Despite of these discoveries, my research has several limitations. First, the study area is limited only in four islands because of time factor and financial problem. All procedures were conducted by one person, so it should have explicitly caused passive sampling. This sort of bias can be identified in the survey season. Although the physiologic traits are evaluated as similar relatively among Coleoptera species, there is a little difference in their activity period. Thus, frequent surveys for preventing the negative effect of passive-sampling were necessary. As regards the problem, one uninhabited island (Hwangdo) was surveyed properly because of scarce time and high cost for reach.

Second, the absence of the Southwest coastal region (Shinan, Mokpo, Jindo and Haenam) data could mislead us to conclude aforementioned interpretation. Because the region accounts for the largest proportion of South Korean islands. Therefore, data recording the region is considerably important among all South Korean insular Coleoptera data. However, researches for the region make slow progress. This must be conducted in the future.

However, in this study, I suggest an importance of locomotivity associated with the wing length or body length of Coleoptera. Although I could not analyze all of dispersal mechanism of insular Coleoptera, the fact that dispersal ability still affects the species

composition in some regions with several conditions (i.e. strongly-nested pattern and weak human disturbance) was analyzed and proposed.

This research can be used as basic data about South Korean Coleoptera, especially about Coleoptera species which inhabit the four islands-Sapsido, Hodo, Nokdo and Oeyeondo. I also expect that it will be applied to protective subset areas in cities. It can be used to decide the area size and distance between protective subset areas in the view of policy making.

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APPENDIX

Appendix 1. The set-up time and location of pit-fall trap

Name	Location	Time (2017yr)	Name	Location	Time (2017yr)
Sapsido	36.349N,126.354E	07.24.15-07.26.11 (44h)	Hodo	36.297N,126.263E	08.27.16-08.29.10 (42h)
Sapsido	36.342N,126.360E	07.24.15-07.26.11 (44h)	Nokdo	36.278N,126.269E	06.16.12-06.18.08 (44h)
Sapsido	36.344N,126.355E	07.24.15-07.26.11 (44h)	Nokdo	36.275N,126.269E	06.16.13-06.18.08 (43h)
Sapsido	36.338N,126.366E	07.24.16-07.26.11 (43h)	Nokdo	36.276N,126.265E	06.16.14-06.18.08 (42h)
Sapsido	36.336N,126.360E	07.24.16-07.26.12 (44h)	Nokdo	36.269N,126.264E	06.16.14-06.18.08 (42h)
Sapsido	36.333N,126.359E	07.24.16-07.26.12 (44h)	Nokdo	36.269N,126.265E	06.16.15-06.18.09 (42h)
Sapsido	36.332N,126.360E	07.24.17-07.26.12 (43h)	Nokdo	36.267N,126.266E	06.16.15-06.18.09 (42h)
Sapsido	36.332N,126.359E	07.24.17-07.26.12 (43h)	Nokdo	36.268N,126.265E	06.16.15-06.18.09 (42h)
Sapsido	36.333N,126.349E	08.02.14-08.04.08 (42h)	Nokdo	36.275N,126.269E	08.29.12-08.30.17 (29h)
Sapsido	36.337N,126.348E	08.02.14-08.04.08 (42h)	Nokdo	36.268N,126.264E	08.29.12-08.30.17 (29h)
Sapsido	36.338N,126.356E	08.02.15-08.04.08 (41h)	Oeyeondo	36.229N,126.083E	06.18.12-06.20.09 (45h)

Sapsido	36.344N,126.354E	08.02.16-08.04.09 (41h)	Oeyeondo	36.230N,126.082E	06.18.12-06.20.09 (45h
Sapsido	36.352N,126.358E	08.02.16-08.04.09 (41h)	Oeyeondo	36.226N,126.087E	06.18.12-06.20.09 (45h
Hodo	36.302N,126.269E	06.14.16-06.16.10 (42h)	Oeyeondo	36.230N,126.080E	06.18.12-06.20.09 (45h
Hodo	36.300N,126.266E	06.14.16-06.16.10 (42h)	Oeyeondo	36.228N,126.080E	06.18.12-06.20.09 (45h
Hodo	36.300N,126.262E	06.14.16-06.16.10 (42h)	Oeyeondo	36.225N,126.085E	06.18.12-06.20.09 (45h
Hodo	36.299N,126.264E	06.14.17-06.16.10 (41h)	Oeyeondo	36.227N,126.074E	09.13.16-09.15.07 (39h)
Hodo	36.299N,126.263E	06.14.17-06.16.10 (41h)	Oeyeondo	36.228N,126.083E	09.13.16-09.15.07 (39h)
Hodo	36.297N,126.264E	06.14.18-06.16.10 (40h)	Oeyeondo	36.231N,126.081E	09.13.17-09.15.07 (38h)
Hodo	36.302N,126.269E	08.27.15-08.29.10 (43h)	Oeyeondo	36.227N,126.075E	09.13.17-09.15.07 (38h)
Hodo	36.300N,126.266E	08.27.15-08.29.10 (43h)	Oeyeondo	36.226N,126.086E	09.13.17-09.15.07 (38h)
Hodo	36.299N,126.264E	08.27.15-08.29.10 (43h)	Oeyeondo	36.230N,126.083E	09.13.17-09.15.07 (38h)
Hodo	36.298N,126.261E	08.27.15-08.29.10 (43h)	Oeyeondo	36.230N,126.079E	09.13.17-09.15.07 (38h)

Appendix 2. Calculated nestedness temperature for each site

Site	TotalOcc	Temp	UnAbsOcc	Site	TotalOcc	Temp	UnAbsOcc
1	36	1.68	31	79	1	1.45	5
2	17	1.2	14	80	1	2.81	5
3	15	3.04	12	81	2	0.7	6
4	65	0.27	224	82	5	4.17	6
5	64	0.08	122	83	1	1.44	3
6	28	1.61	23	84	2	0.39	6
7	64	0.14	19	85	5	2.83	9
8	43	1.06	34	86	2	0.15	6
9	37	1.68	31	87	3	0.04	5
10	34	2.2	26	88	2	0.11	6
11	44	2.83	39	89	2	0.83	6
12	42	5.71	35	90	3	0.05	3
13	1	5.29	5	91	4	0.21	7
14	3	2.25	6	92	3	0	3
15	5	6.22	9	93	1	0.01	2
16	8	3.53	10	94	1	0.18	6
17	6	4.09	11	95	2	0.4	4
18	6	2.3	8	96	1	0.4	5
19	1	2.27	1	97	3	0.96	6
20	5	0.78	5	98	2	0.72	5
21	3	0.95	6	99	2	0.23	6
22	2	0.46	4	100	3	0.99	7
23	7	0.69	11	101	2	0.01	5
24	2	1.3	2	102	5	0.41	6
25	2	2.56	4	103	1	0.05	5
26	9	1.7	11	104	15	5.88	17
27	1	1.69	4	105	6	3.23	8
28	7	7.14	8	106	6	3.65	10
29	1	0.05	5	107	6	3.8	9
30	2	0.48	6	108	6	2.39	10
31	46	2.53	45	109	2	0.09	6
32	48	2.45	47	110	1	5.38	1
33	4	0.35	7	111	3	0.65	5

34	15	1.34	11	112	21	3.42	17
35	6	0.22	5	113	3	0.84	4
36	7	0.37	5	114	8	0.66	8
37	5	0.57	3	115	4	0.77	5
38	6	0.09	8	116	3	1.42	7
39	7	1.16	7	117	3	1.04	6
40	1	0.11	5	118	18	11.06	15
41	1	0.16	1	119	5	5.76	9
42	5	1.62	7	120	5	2.63	8
43	2	5.23	5	121	6	3.62	4
44	2	0.28	6	122	7	1.48	9
45	3	0.22	5	123	7	0.13	5
46	1	2.74	5	124	8	0.16	5
47	1	0.15	3	125	2	0.18	5
48	2	0.14	5	126	8	1.19	10
49	1	0.07	1	127	9	1.25	7
50	45	0.34	38	128	5	0.52	7
51	1	0.74	3	129	3	0.62	5
52	2	2.96	6	130	7	0.58	6
53	3	0.28	6	131	9	0.53	10
54	3	1.96	5	132	5	0.5	7
55	2	0.16	6	133	3	1.05	6
56	2	2.97	6	134	2	0.84	6
57	4	0.44	6	135	6	0.89	5
58	6	1.49	5	136	5	0.33	8
59	4	0.49	7	137	2	3.95	6
60	4	0.3	4	138	3	0.57	7
61	2	0.02	4	139	1	3.57	5
62	2	0.27	2	140	5	0.42	3
63	5	1.47	4	141	5	7.12	8
64	8	0.1	9	142	7	0.18	7
65	8	0.56	10	143	3	0.31	3
66	6	0.47	7	144	12	9.84	16
67	2	0.09	4	145	1	2.06	5
68	7	0.2	7	146	3	3.11	6
69	3	0.79	4	147	5	4.6	4
70	19	6.97	20	148	3	0.53	7

71	4	9.68	10	149	7	0.55	7
72	14	1.87	11	150	1	1.73	3
73	58	7.44	56	151	1	5.12	5
74	1	3.86	3	152	6	2.98	8
75	1	10.44	5	153	2	4.46	4
76	4	1.19	6	154	2	1.33	6
77	2	0.18	5	155	3	0.49	3
78	2	2.85	5	156	22	16.33	29

Appendix 3. Calculated nestedness temperature for each species

Species	TotalOcc	Temp	UnAbsOcc	Species	TotalOcc	Temp	UnAbsOcc	Species	TotalOcc	Temp	UnAbsOcc
aa	8	0.2	6	fl	1	0.7	2	kw	6	0.61	7
ab	6	0.29	3	fm	1	3.45	2	kx	9	0.17	10
ac	1	0.32	1	fn	2	2.2	3	ky	8	1.63	9
ad	2	14.82	3	fo	2	14.19	3	kz	4	0.56	6
ae	1	0.24	1	fp	2	0	0	la	2	0.02	3
af	1	0.78	2	fq	1	0	1	lb	1	0.1	2
ag	4	1.85	5	fr	2	0.05	3	lc	1	4.08	2
ah	3	1.47	4	fs	2	0.08	3	ld	1	3.13	1
ai	1	6.36	1	ft	1	0.09	2	le	8	1.49	10
aj	1	1.36	1	fu	12	0.14	13	lf	1	0.04	1
ak	1	1.49	1	fv	5	2.28	7	lg	1	3.6	1
al	2	0.57	3	fw	4	3.1	6	lh	2	0.61	3
am	2	0	0	fx	1	0.42	2	li	3	0.63	5
an	3	0	1	fy	3	0.3	4	lj	1	3.61	1
ao	4	0.57	2	fz	6	0.14	4	lk	3	2.72	5
ap	2	0.16	2	ga	51	0.11	65	ll	1	0.83	1
aq	2	0.1	4	gb	53	4.19	75	lm	1	0.84	1
ar	1	0.13	1	gc	1	1.08	1	ln	1	1.88	1
as	1	0.28	1	gd	3	1.62	5	lo	1	0	1
at	1	0.01	2	ge	56	0.35	82	lp	2	1.17	3
au	1	0.01	2	gf	20	0.05	51	lq	1	0.08	1
av	1	0.02	2	gg	5	1.35	3	lr	3	0.04	4
aw	1	0.02	2	gh	12	0.19	11	ls	1	1.49	1
ax	1	0.02	2	gi	9	0.16	8	lt	2	0	0
ay	1	0.02	2	gj	1	0	1	lu	4	0.12	4
az	1	0.02	2	gk	3	0.11	4	lv	3	0.52	5
ba	1	0.02	2	gl	7	0.82	9	lw	2	0.21	3
bb	1	0.02	2	gm	2	1.09	4	lx	1	0.02	1
bc	1	0.03	2	gn	1	0.25	1	ly	1	0.02	1
bd	1	0.03	2	go	1	1.99	1	lz	1	0.02	1
be	2	0.1	2	gp	1	5.57	1	ma	5	2.32	7
bf	1	0	1	gq	2	3.89	4	mb	2	0.07	3
bg	1	0.06	1	gr	1	1.5	1	mc	1	2.12	1

bh	1	0.87	1	gs	1	5.44	1	md	1	4.45	1
bi	1	0.71	1	gt	1	6.22	1	me	1	1.08	1
bj	1	0.81	1	gu	1	7.97	1	mf	2	0	0
bk	1	0.99	1	gv	1	5.65	1	mg	2	7.43	3
bl	4	0.68	5	gw	5	0.4	6	mh	1	5.88	1
bm	1	0.03	1	gx	13	0.2	12	mi	2	1.45	3
bn	2	0.11	3	gy	5	1.15	7	mj	1	0.72	1
bo	4	0.02	2	gz	3	0.05	1	mk	2	8.39	3
bp	2	0.08	3	ha	3	0.26	4	ml	3	0.12	4
bq	2	0.13	3	hb	1	13.62	1	mm	1	0.76	1
br	1	1.29	1	hc	1	0	0	mn	3	0.24	5
bs	2	2.92	3	hd	7	0.25	8	mo	3	0.02	3
bt	1	1.29	1	he	4	1.26	6	mp	7	0.11	7
bu	2	4.46	3	hf	3	0.14	1	mq	2	0.18	1
bv	1	9.61	1	hg	1	0.16	1	mr	1	0.6	1
bw	1	6.08	1	hh	4	1.74	4	ms	4	0.07	3
bx	1	0.99	1	hi	2	1.1	2	mt	1	0.01	1
by	1	2.94	1	hj	7	0.15	8	mu	1	0.01	1
bz	1	0.05	2	hk	3	0.16	5	mv	10	0.33	11
ca	3	2.23	5	hl	1	0.54	1	mw	5	0.18	7
cb	1	0.16	2	hm	4	0.11	5	mx	4	1.78	5
cc	2	7.69	3	hn	2	0.1	4	my	1	5.29	1
cd	1	0.5	2	ho	1	2.84	1	mz	6	0.36	8
ce	1	0	0	hp	2	0.18	3	na	4	0.22	5
cf	1	4.02	2	hq	1	9.39	1	nb	1	0.05	1
cg	1	4.11	2	hr	1	1.34	1	nc	1	0.05	1
ch	1	4.13	2	hs	1	0.97	1	nd	1	0.76	1
ci	1	0	0	ht	1	1.45	1	ne	2	1.5	3
cj	1	0.1	2	hu	1	1.56	1	nf	4	0.44	6
ck	5	2.14	7	hv	2	1.86	3	ng	1	0.95	1
cl	4	0.27	6	hw	1	0.57	2	nh	2	0.04	3
cm	4	4.31	6	hx	1	0.28	2	ni	3	0.39	5
cn	6	0.28	5	hy	1	0.28	2	nj	5	1.28	7
co	5	1.12	4	hz	5	0.32	5	nk	1	1.03	1
cp	1	0.01	2	ia	1	0.18	2	nl	1	1.05	1
cq	2	0.69	3	ib	2	0.43	3	nm	1	2.52	1
cr	1	0.14	2	ic	1	0	1	nn	3	0.29	5

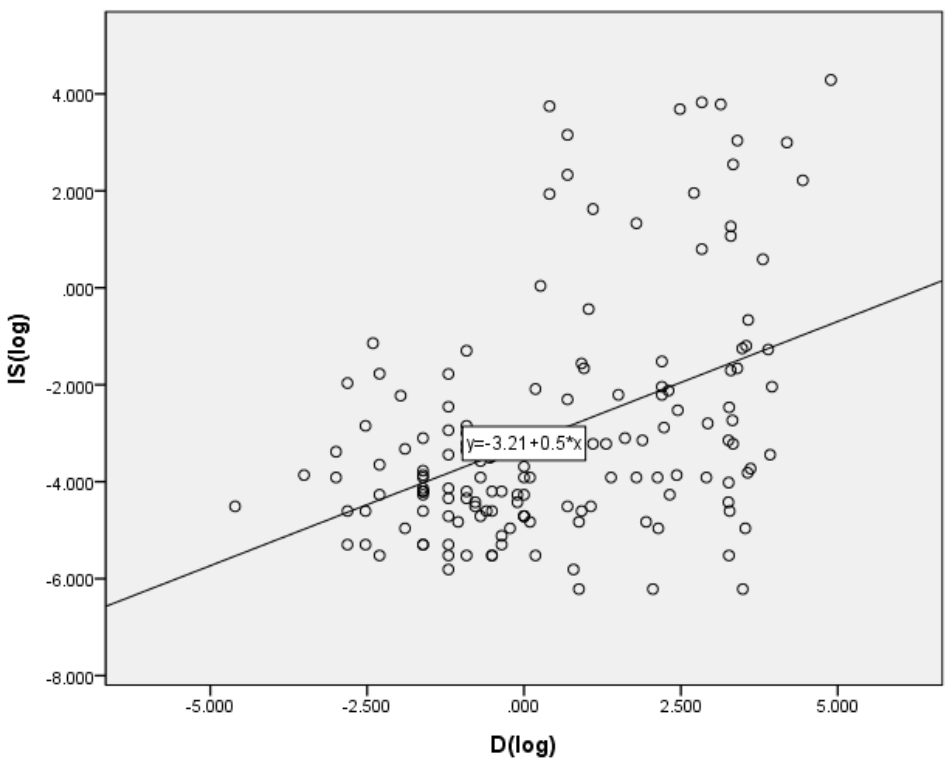
cs	8	0.83	10	id	1	0	1	no	1	0.65	1
ct	4	3.82	6	ie	2	0	0	np	1	0.67	1
cu	1	1.11	2	if	3	0.13	5	nq	2	0.11	3
cv	1	3.18	2	ig	12	2.04	11	nr	1	1.03	1
cw	1	1.71	2	ih	1	0	0	ns	1	1.06	1
cx	1	9.21	2	ii	3	1.68	3	nt	1	1.08	1
cy	4	0.49	5	ij	3	0.06	2	nu	1	1.11	1
cz	4	0.66	6	ik	4	0.13	2	nv	2	0.04	3
da	6	0.34	5	il	3	1.09	3	nw	1	0.33	1
db	2	0.05	3	im	2	0	0	nx	1	0.34	1
dc	4	0.01	2	in	9	0.18	8	ny	1	0.35	1
dd	2	0.51	3	io	1	0	1	nz	1	0.36	1
de	1	1.34	1	ip	1	0.04	2	oa	2	4.76	3
df	37	0.25	77	iq	1	0.29	2	ob	1	0.24	1
dg	1	0.05	1	ir	4	2.45	5	oc	1	7.94	1
dh	1	1.43	1	is	1	0.01	2	od	1	7.09	1
di	1	0.09	1	it	1	0.12	2	oe	1	2.71	1
dj	1	0.05	1	iu	1	0.09	2	of	1	2.77	1
dk	1	0.06	1	iv	2	0.4	3	og	4	2.66	6
dl	0	0	0	iw	1	1.71	2	oh	1	3.32	1
dm	6	0.16	4	ix	2	3.95	3	oi	1	8.77	1
dn	6	6.5	7	iy	1	7.83	2	oj	1	2.82	1
do	4	0.04	4	iz	1	0.36	2	ok	3	0.07	3
dp	5	0.13	5	ja	1	0.23	2	ol	2	1.67	3
dq	2	0	0	jb	6	0.85	8	om	1	0.18	1
dr	2	0	0	jc	2	3.6	3	on	6	0.14	7
ds	1	0.01	1	jd	19	0.65	24	oo	2	0.12	3
dt	2	1.63	2	je	6	12.93	8	op	1	0.07	1
du	2	0.21	2	jf	4	0.3	4	oq	5	0.2	7
dv	3	0.29	5	jg	1	0.17	2	or	1	1.81	1
dw	1	2.09	1	jh	16	0.35	8	os	2	6.57	3
dx	1	2.06	1	ji	3	0.1	5	ot	1	8.41	1
dy	14	0.06	11	jj	3	0.1	4	ou	1	8.12	1
dz	10	0.17	9	jk	4	0.86	5	ov	1	4.34	1
ea	1	4.15	1	jl	2	2.28	3	ow	1	4.69	1
eb	3	2.84	3	jm	1	0.18	2	ox	1	4.57	1
ec	11	0.47	12	jn	1	0	0	oy	1	4.69	1

ed	2	0	0	jo	14	0.02	11	oz	1	0.65	1
ee	2	0	0	jp	5	1.2	3	pa	1	0.69	1
ef	11	4.2	8	jq	1	0	1	pb	1	0.73	1
eg	4	0.16	5	jr	20	0.2	31	pc	1	0.77	1
eh	3	0.18	3	js	1	0.92	2	pd	1	0.81	1
ei	1	0	1	jt	4	0.31	2	pe	8	1.31	10
ej	1	0	1	ju	1	0	0	pf	5	3.61	7
ek	1	0	1	jv	1	0.12	2	pg	7	5.7	9
el	5	0.64	6	jw	10	0.79	13	ph	1	11.39	1
em	1	1.06	2	jx	2	7.54	4	pi	1	7.79	1
en	1	0.4	2	jy	1	0.3	2	pj	1	7.98	1
eo	1	0.28	2	jz	2	0.77	4	pk	1	11.87	1
ep	5	0.1	6	ka	1	3.1	2	pl	1	6.26	1
eq	1	0.04	2	kb	1	0.07	2	pm	4	0.27	6
er	5	0.26	3	kc	1	7.6	2	pn	2	0.66	3
es	2	0.17	4	kd	1	0.32	2	po	1	1.69	1
et	5	0.61	7	ke	4	3.27	4	pp	1	9.26	1
eu	13	0.26	10	kf	1	0	0	pq	1	4.62	1
ev	1	0	1	kg	4	0.34	4	pr	2	0.08	3
ew	1	0	1	kh	3	1.23	3	ps	1	8.88	1
ex	16	0.13	17	ki	3	0.13	3	pt	1	9.19	1
ey	3	5.33	5	kj	1	0.24	2	pu	0	0	0
ez	2	0.04	4	kk	5	0.19	7	pv	1	6.95	1
fa	1	0.03	2	kl	2	1.48	4	pw	1	4.95	1
fb	3	1.05	5	km	1	0.48	2	px	1	13.93	1
fc	2	0.03	2	kn	1	0.49	2	py	1	13.72	1
fd	1	0.27	2	ko	1	0.49	2	pz	1	4.47	1
fe	3	0.33	5	kp	1	0.5	2	qa	1	5.07	1
ff	1	0.12	2	kq	3	0.46	5	qb	1	12.35	1
fg	2	0.11	4	kr	1	0.51	2	qc	1	14.53	1
fh	2	0.21	4	ks	1	0.45	2	qd	1	12.47	1
fi	15	0.07	18	kt	6	0.78	7	qe	1	13.09	1
fj	1	0.1	2	ku	3	5.45	5				
fk	2	15.03	4	kv	7	2.13	8				

Appendix 4. Multicolinearity between island size and island distance

IS = the island size of South Korean islands (㎢, logged)

D = the island distance from mainland of South Korea (㎞, logged)

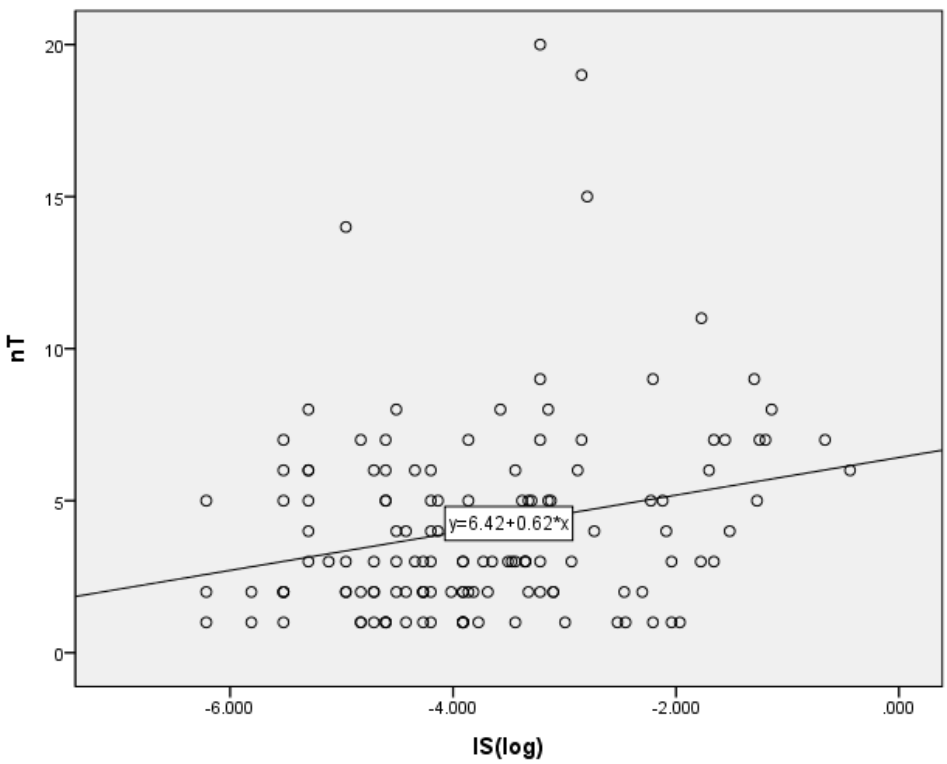


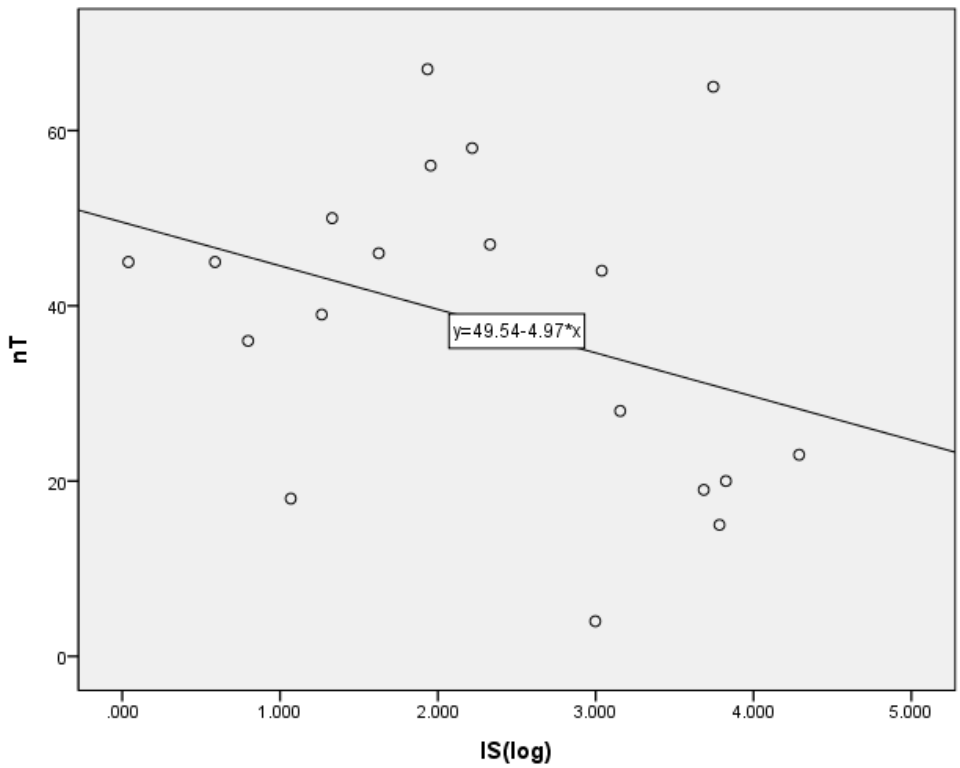
Appendix 5. Difference between rate of increase of the number of Coleoptera species in relation to island size

i) IS(log)<0 : y=6.42+0.62x

ii) IS(log)>0 : y=49.54−4.97x

IS = the island size of South Korean islands (㎢, logged)




y=49.54-4.97*x
nT
60
40
20
0
.000
1.000
2.000
3.000
4.000
5.000
lS(log)

국 문 초 록

국내 도서 딱정벌레의 섬 생물지리학적 연구

섬의 크기와 본토로부터 떨어진 거리 등 물리적 환경이 도서지역의 생물다양성에 영향을 준다는 섬 생물지리학이 대두된 이후, 이를 여러 고립 환경에 적용하려는 시도가 현재까지 이어지고 있다. 그러나 우리나라와 같이 도서지역이 본토로부터 가깝고 오래 전부터 인간 활동이 존재한 경우 섬의 물리적 환경 외에 인간의 교란의 영향이 생물다양성에 영향을 줄 가능성이 존재한다. 이에 따라 본 연구에서는 우리나라 도서지역의 딱정벌레의 분포 양상을 파악하였고, 실제로 딱정벌레의 종 다양성에 섬의 크기와 본토로부터의 거리가 미치는 영향을 측정하였으며, 직접 표본을 채집하여 검증함으로써 딱정벌레의 분포 양상의 구체적인 원인을 추측하였다.

nestedness 분석 결과 전체 도서지역 딱정벌레 분포가 상당히 견고한 nestedness를 지니고 있는 것으로 확인되었고 특정 종을 중심으로 지리적인 권역 형성이 가능하였다. 또한 남동해안 지역에 비해 서해안 지역이 nestedness가 더 높아, 서해안 지역이 상대적으로 본토로부터의 외래종 침입 등 외부 교란이 적은 것으로 판단된다.

종 다양성과 섬의 물리적 환경 사이의 관계에서는 섬의 크기가 종 다양성과 정비례 관계를 보였다. 그러나 일정 크기 이상인 유인도에서는 오히려 반비례 관계를 보였는데, 이는 섬의 면적이 넓어질수록 부양가능한 인구가 늘어나 강하고 지속적인 인간 교란이 이루어지기 때문인 것으로 해석된다. 본토로부터의 거리는 종 다양성과 상관성이 없는 것으로 나타났으나, nestedness가 높은 지역들에서는 장시성 종의 다양성과 본토로부터의 거리가 정비례 관계를 보였다. 이는 외부 교란이 적은 상태에서는 단시성 종에 비해 장시성 종이 자력으로 도달하여 군집화에 성공하는 것이 상대적으로 쉽기 때문임을 보여주는 것으로 판단된다.

날개 길이의 차이에 따른 도서지역 딱정벌레 분포상 차이를 검증하기 위해 충청남도 보령군 일대의 네 섬(삽시도, 호도, 녹도,

외연도)을 답사하여 함정채집 및 임의채집을 통해 표본을 총 755개 확보하여 동정한 결과 본토로부터 멀어질수록 섬의 우점도가 감소하면서 장시성 종 비율이 늘어나는 경향을 보였다. 이는 단시성 종에 비해 한정된 공간에서 군집화가 느리고 개체수도 적은 장시성 종의 특성 때문인 것으로 판단된다. 따라서 인간의 영향이 크지 않은 경우 딱정벌레의 날개 길이에 따른 분산 능력의 차이가 도서지역 딱정벌레 종 조성에 영향을 미치고 있는 것으로 짐작된다.

본 연구는 우리나라 딱정벌레의 분포 양상과 그 기제에 대한 기초자료를 제공하였으며, 아직 조사되지 않은 섬들의 종 조성 및 종 다양성의 예측에 활용될 수 있을 것으로 판단된다. 또한 실제 우리나라 도서지역에서 고전적인 섬 생물지리학 이론과 인간의 교란이 각각 영향을 미치는 수준에 대하여 본격적으로 탐구한 점에서 의의가 있다.

주요어 : 섬 생물지리학, 종 다양성, 딱정벌레, 장시성, 단시성
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